LUMBAR PUNCTURE AND SPINAL ANALGESIA

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LUMBAR PUNCTURE AND SPINAL ANALGESIA

BY

SIR ROBERT MACINTOSH

M.A., D.M., F.R.C.S. (Edin.), F.F.A.R.C.S.
M.D. (hon. causa), Buenos Aires and
Aix-Marseilles, Hon. F.F.A.R.A.C.S.
Nuffield Professor of Anaesthetics,
University of Oxford.

Illustrated by
MISS M. McLARTY AND
MISS MARJORIE BECK

SECOND EDITION

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PREFACE TO SECOND EDITION

A NUMBER of small alterations and improvements have been made in the script of this second edition. The 110 original illustrations, too, have been carefully revised and minor inaccuracies eliminated. For help in accomplishing this I am greatly indebted to John Kirk, Emeritus Professor of Anatomy in the University of London, and to Dr. H. G. Epstein and Miss Marjorie Beck of this Department. Miss E. M. Slatter has been good enough to overhaul the references, bringing them into line with the system recommended by the Publishers.

R. R. MACINTOSH.

NUFFIELD DEPARTMENT OF ANAESTHETICS,
UNIVERSITY OF OXFORD.
1957.

PREFACE TO THE FIRST EDITION

THE literature on lumbar puncture and spinal analgesia is abundant enough to make an explanation necessary for any addition to it. The reasons for another book on this subject are various. Although lumbar puncture is often entrusted to the newly-qualified house doctor, it is seldom that he has had any instruction on how to carry it out. It is difficult to find a concise exposition of the technique to which he can refer; and the result is that early attempts are frequently and unnecessarily bungled. That is why I have included in this book the things I should have liked to have readily available for myself when setting out on my first lumbar punctures and spinal anaesthetics. A road-map is often a useful thing to have when one is exploring an unfamiliar locality.

The second reason is that some surgeons, encouraged by the fact that they are expert at lumbar puncture, have been tempted to take the further step of giving their own spinal anaesthetics: in which case, not infrequently, their lack of knowledge of basic principles leads them into difficulties. "The apparent simplicity of the manoeuvre constitutes its greatest danger in the hands of the tyro."[1] "The factor most contributory to its tragic history is the ease with which it can be performed by anyone."[2] Forty-nine

years intervened between the writing of the last two sentences. The quip that Pentothal is fatally easy to give, still has its counterpart in spinal anaesthetics. A patient under a spinal anaesthetic should be looked after by a trained anaesthetist. But if for one reason or another, the surgeon has both to operate and to keep an eye on the general condition of the patient, he should at any rate know something about the essentials of the subject and what to do if things go wrong.

A third reason for this book is that members of this Department have thrown light on certain obscure aspects of spinal analgesia, and I feel that the points cleared up will be of interest to others too.

My fourth reason is my desire to take advantage of the collaboration of Miss McLarty, which I have the good fortune to enjoy. Certainly I should not have embarked on this work without her help: for I believe that views on what is largely a technical subject can be conveyed more quickly and, what is more important, with greater accuracy by a few good illustrations than by pages of script. There is much to be said for Corning's observation in 1900: "I advise those who contemplate practising spinal anaesthesia, to to take a look at the skeleton, especially the relations of the lumbar vertebrae. An intelligent glance of that sort is worth many words."[3] I have spent many unattractive but profitable hours working in the post-mortem room and, for the facilities provided, I am grateful to Dr. A. H. Robb-Smith. If a dissection has been fruitful, Miss McLarty has recorded it clearly and with decision; and I am sure that these illustrations will be helpful to those who have no opportunity for dissecting this unfamiliar region. I am indebted, too, to Miss A. Arnott for other valuable illustrations. Some of the pictures may appear almost duplicates, but I include them deliberately where they are likely to help the reader to form a clear mental picture of the structures through which the needle passes on its way to the vertebral canal, and of the obstacles which are likely to be impeding it when it is off course; as well as of what happens to an anaesthetic solution deposited within the dura.

I do not intend to extol the virtues of spinal analgesia. The benefits of any method of pain relief, general or local, have to be paid for in terms of morbidity, and the price exacted of the patient in this respect depends little on the choice of method or agent, but very much on the care, skill and experience of the anaesthetist himself. From a purely selfish point of view, the consequences to

the anaesthetist of carelessness or inexperience are much less serious with a general than with a spinal anaesthetic. Even in the event of death, a sympathetic pathologist has only to stress the unhealthy state of some organ; then everyone, including the anaesthetist himself, if he is complacent enough, will believe the coroner's finding that no one was to blame; and so the incident is soon forgotten. But a grave mistake with a spinal anaesthetic is quite another matter. A paralysed patient wheeled about in a bath-chair is a constant reproach, and does nothing to enhance the reputation of surgeon and anaesthetist concerned. Moreover, in some cases heavy damages have been awarded, although anomalously there would not have been the slightest prospect of this if the patient had been killed outright by a general anaesthetic badly given.

I have to thank my erstwhile Registrar, Dr. A. Crampton Smith, now happily a Consultant, for his skill and care in cutting the bony vertebral sections and for his help in dissecting the specimens from which a number of the drawings were made. Even though the type-script is not extensive I am conscious of, and grateful for, the guidance extended to me by experts in allied subjects, especially Professor T. B. Johnston, Dr. H. G. Epstein, Dr. Grita Weiler and Mr. Lionel Salt. Their help on doubtful points has been a source of considerable comfort.

I have only to add that although at first I intended to confine the scope of this book strictly to practical aspects of lumbar puncture and spinal analgesia, I have extended certain sections to include a few academic points likely to be of interest to the examination candidate.

R. R. MACINTOSH.

NUFFIELD DEPARTMENT OF ANAESTHETICS,
UNIVERSITY OF OXFORD.
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CHAPTER I

Early History

THE introduction of the hollow needle and a conveniently sized glass syringe by Alexander Wood[1] in 1853 and the clinical demonstration of the local anaesthetic properties of cocaine by Koller in 1884[2] were direct steps leading to spinal analgesia. Corning, a neurologist, was the first to give cocaine intradurally, but it is not surprising that this work passed unacclaimed by contemporary workers. It was in 1885 that he injected cocaine into the subarachnoid space, but he did so unintentionally and without recognising what he had done. The result was indeed dramatic, but it is certain that it could not be reproduced at will, either by Corning himself or by anyone else carrying out the technique he described. Corning's experiment was based on faulty physiological and anatomical premises: for he believed that cocaine injected into the region between two spinous processes would be absorbed by veins and "transferred to the substance of the cord, and give rise to anaesthesia of the sensory and perhaps motor tracts of the same."[3]

At this time the aim of any injection was to deposit the drug as near as possible to the site on which it was desired to act. Thus Wood[4,5] believed that the main virtue of his hollow needle was that it deposited morphine in close contact with painful nerves, and for many years physicians continued to consider morphine effective only if injected actually into the painful lesion. Corning was in a dilemma. He wished to deposit the cocaine reasonably close to the cord, and yet avoid the risk of injuring it by puncture. He performed a preliminary experiment on a dog, injecting, at an unstated depth, 20 minims of 2 per cent. cocaine "into the space situated between the spinous processes of two of the inferior dorsal vertebrae." This was followed by loss of sensation, and incoordination of the hind legs. The fact that the effect had not spread to the forelegs was attributed to "the lethargy of the circulation at this point."

After this he carried out his now well-known experiment on man. He had noted that in the lower thoracic region the transverse

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of the greatest significance when considering the spread of injected fluid. If the tip of the needle lies superficial to the ligamentum flavum, the effect of the injection is nil. Even if the tip penetrates the ligament and lies within the extradural space, the effect of 3-4 cc. of 3 per cent. cocaine is negligible. If, inadvertently, the needle happens to have been inserted a fraction of an inch further on, the dura is pierced and the wide spread of the injected fluid in the cerebro-spinal fluid gives striking results. The dripping of cerebro-spinal fluid through the needle, the sure sign that the dura has been entered, was denied to Corning because, as his article makes clear, he introduced his needle with a charged syringe already attached.

In 1894 this prolific writer published another book of essays,[4] some, rehashes of previous articles, others, of mixed value, so that it is not surprising that two arresting paragraphs passed unnoticed at the time even by his own countrymen. Under the heading "The irrigation of the cauda equina with medicinal fluids," he wrote "... I became impressed with the desirability of introducing remedies directly into the spinal canal with a view to producing still more powerful impressions on the cord, and more especially on its lower segment." He introduced a small director (p. 106) half an inch long between the spines of L. 2-3 and through this passed a fine needle deliberately to perform lumbar puncture. But this was three years after the technique of lumbar puncture had been described in detail by Quincke. Into the first of his two patients Corning injected a mixture of aconite and cocaine to medicate the cord because of "spinal irritation" ten days after an operation on the urethra. Five to eight minutes after the puncture subjective feelings were experienced, and in a quarter of an hour all pain had gone; and when it did come back some hours afterwards, it was less than before. In the second case, "the injection was made with the hope of relieving the severe vesical and abdominal pains" which are a peculiarly distressing feature of caisson disease, then common because of the building of the tunnel under the Hudson River. As well as in these two cases, he had "occasionally resorted to the procedure in properly selected cases."

In 1885, Corning finished his article describing the patient to whom he had introduced cocaine unwittingly and unknowingly into the subarachnoid space with the following dramatic passage:

processes of the vertebrae lie at the same depth as the laminae which form the posterior boundary of the vertebral canal. He therefore first inserted the needle lateral to the midline until the point touched the transverse process, and adjusted the marker on the shaft of the needle to skin level (Fig. 1). The needle was

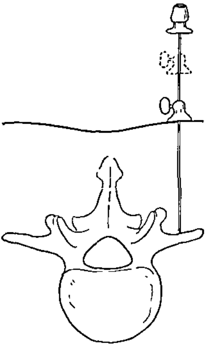

FIG. 1

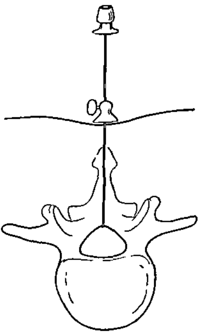

FIG. 2

then reinserted, this time in the midline between two spines, but as a guarantee against injury to the cord, not quite up to the marker (Fig. 2). He now injected—with what object it is not clear —60 minims of 3 per cent. cocaine " into the space situated between the spinous processes of the 11th and 12th dorsal vertebrae," of a man who suffered from "spinal weakness and seminal incontinence." Ten minutes later the legs felt sleepy, and later still there was complete analgesia of legs and perineum. If these directions are followed, the tip of the needle will lie roughly at the depth of the ligamentum flavum, and in the hands of a cautious contemporary investigator trying to corroborate Corning's findings, well proximal to it. Corning does not mention the ligamentum flavum nor the dura mater: yet such anatomical boundaries are

attention at the time, and it is certain that they had no influence upon the ultimate adoption of spinal analgesia in surgery.

Wynter[10] in 1891 briefly described two cases in which he had performed lumbar puncture with Southey's tubes, to allow continuous drainage of cerebro-spinal fluid in an attempt to treat tuberculous meningitis. A few months later, Quincke[11] acknowledging Wynter's work, described the technique of lumbar puncture, essentially the same as that practised to-day, and showed how the cerebro-spinal fluid pressure could be relieved by simple puncture. The practice of present day spinal analgesia is a direct consequence of this admirable article. The withdrawal of fluid proved disappointing as a therapeutic procedure: but soon hope was transferred from simple withdrawal to replacement of the fluid by a solution which would come into contact with the region which it was desired to treat. Ziemssen[12] suggested this after injecting methylene blue intrathecally into corpses, and Sicard[13, 14] after preliminary work on animals, injected anti-tetanic serum by the same route into a patient with tetanus.

The first two publications on spinal analgesia for surgical operations were made in 1899. At the time of their investigations neither author knew of the work of the other, but both acknowledged their indebtedness to Quincke. Bier's article[15] which preceded Tuffier's[16] by a few months, describes six patients to whom he had given 10-20 mg. cocaine intrathecally for operations on the lower limb. The question of sterility is not mentioned, and since he used tap water to dissolve the cocaine crystals[17] and placed his finger over the hub of the needle to lose as little cerebro-spinal fluid as possible,[15] it is not surprising that headache and vomiting were marked features of convalescence. These unpleasant after-effects are described as being as bad as those after chloroform and ether, with the added disadvantage that they sometimes last longer. In order to investigate their causation, Bier asked that a spinal anaesthetic should be given to him. Lumbar puncture was performed, but as the syringe would not fit the needle, " much cerebro-spinal fluid was lost, and the major part of the cocaine came out of the side." His assistant, Hildebrant, offered himself as a substitute, and that 5 mg. cocaine eliminated pain is clear from the exacting tests which included pulling the pubic hair, hard pressure on and pulling of the testes, and a sharp blow with an iron hammer on

"Whether the method will ever find an application as a substitution for etherisation in genito-urinary or other branches of surgery, further experience alone can show. Be the destiny of the observation what it may, it has seemed to me, on the whole, worth recording." These two sentences have often been taken incorrectly from their context to give Corning credit for the introduction of spinal analgesia. It is strange that in 1894, when he purposefully introduced mixtures containing cocaine into the subarachnoid space, he did not realise that the case he reported in 1885 was one of inadvertent spinal analgesia, and that there was now a more dependable method of achieving this which would allow certain surgical operations to be performed without general anaesthetics.

There was, however, a defect in Corning's technique which made it not nearly as reliable as it would at first appear. The needle, before it was introduced through the skin, was screwed on to the nozzle of the syringe already charged with solution. It was then a matter of hit or miss, with the latter a strong probability. The needle was inserted and the solution injected; and such a procedure would necessarily lead to a percentage of failures high enough to be discouraging. Present-day spinal analgesia would soon be abandoned if, before injection, the anaesthetist did not confirm that the point of the needle lay within the dural sac. Even after spinal analgesia for surgery had been generally accepted, such blind shots appear to have been commonplace, for many writers found it necessary to stress that the solution should not be injected until cerebro-spinal fluid was seen to issue from the needle.[7] On one occasion the anaesthetist, having introduced his needle, accepted a shooting pain down the leg as his clue to inject.[8] A glance at figure 73 suffices to explain why the resultant analgesia was restricted. See also text on page 52.

Corning appears to have regarded his intentional intrathecal injection only as a means of alleviating existing pain. He overlooked its possibilities in surgery. One is reminded of the part played by Humphry Davy[9] in the discovery of general anaesthetics. He recorded when inhaling nitrous-oxide experimentally that the pain caused by an erupting wisdom tooth was relieved; but he did nothing further about the matter and his observation had no direct bearing on the introduction of general anaesthetics some forty-six years afterwards. Similarly, Corning's writings attracted no

attention at the time, and it is certain that they had no influence upon the ultimate adoption of spinal analgesia in surgery.

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the shin! These experiments, which started at 7.30 in the evening, were followed by dinner, wine and cigars. Both volunteers were in poor shape for a few days afterwards. Bier's symptoms of headache and dizziness, relieved when he lay down, could easily be attributed to leakage of cerebro-spinal fluid, and those of Hildebrant, which included vomiting, suggest that the cause was meningeal irritation.

Bier's article includes some pertinent observations resulting from his own experience, and ends by saying that he does not feel justified in continuing his work on humans without carrying out animal experiments with a view to eliminating vomiting. Further communications by Bier followed[18, 19] but, unlike the wholly enthusiastic reports from American and French sources, his observations continued to sound a note of caution. By 1904, writing with Donitz,[20] he felt justified in stating "after many disappointments we believe now that we can recommend spinal anaesthesia," and then qualified this by adding, "although it is still capable of and needs plenty of improvement."

Tuffier[16] first tried cocaine intrathecally to relieve the pain of sarcoma of the leg in a young man on whom morphine was losing its effect. Even if only temporary, "the results were truly remarkable." He then gave a similar injection to a young woman with painful recurrent sarcoma of the thigh, and to his great surprise was able to remove the tumour without causing any discomfort. He operated rapidly, but remarked that haste was unnecessary as analgesia lasted more than an hour. It was only after this that he heard of Bier's publication. Tuffier's short paper pointed out that spinal analgesia was satisfactory for vaginal hysterectomy, but not for abdominal operations. By the time of his much more extensive contribution in January 1901,[21] he had improved his own technique by vigorous attention to asepsis, by altering the height of puncture, and by putting the patient in different positions immediately the injection had been carried out. In this way he had extended the field of operation from the perineum to the abdominal cavity and higher, as his list of organs operated on included kidney, stomach and breast. The article has a particularly good section on technique. He discusses headache fully, acknowledges an incidence

of 40 per cent., points out that beyond causing discomfort to the patient the complication is not serious, and adds "the explanation of it will come later." He is the first to record a follow up examination of patients operated on under spinal analgesia: in sixty operated on between six and thirteen months previously, he found no complications attributable to the anaesthetic.

For some years, most of the work on spinal analgesia came from the Continent, and this was probably accounted for by the poor standard of general anaesthesia prevailing there. From America, early contributions came from Matas,[22] and Tait and Caglieri,[23] but the literature on this subject from England was very meagre until Barker[24] wrote his classical article in 1907.

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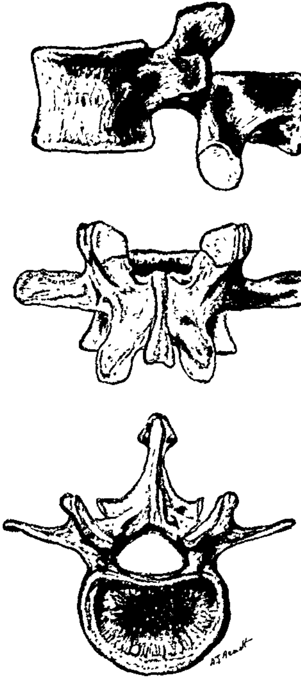

FIG 3

Corning.[1] "I advise those who contemplate
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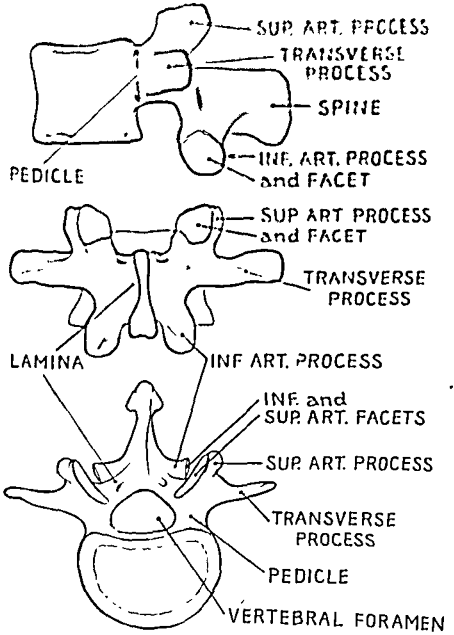
SUP. ART. PROCESS
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INF. ART. PROCESS and FACET
PEDICLE
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TRANSVERSE PROCESS
LAMINA
INF ART. PROCESS
INF. and SUP. ART. FACETS
SUP. ART. PROCESS
TRANSVERSE PROCESS
PEDICLE
VERTEBRAL FORAMEN

FIG. 4

CHAPTER II

Anatomy

IT is important that the anaesthetist should possess a good knowledge of the anatomy of the lumbar vertebrae, since it is in this region that a needle can be introduced into the spinal canal most safely and easily. He must be familiar also with the disposition of the three membranes which envelop the central nervous system. In the vertebral canal these three tubular membranes enclose the cord in an elongated compartment—annular in cross section—the subarachnoid space (Fig. 20) in which a local anaesthetic solution can be made to spread to any desired height after it has been introduced low down in the lumbar region.

Vertebral Column

One of the main functions of the vertebral column is to protect the spinal cord. A typical vertebra is made up of:—

1. A body which bears and transmits weight, and forms the base for

2. An arch, composed of pedicles and laminae, which surround and protect the cord laterally and posteriorly.

There are seven projections from these vertebral or neural arches. They are:—

(*a*) Three muscular processes—two transverse and one spinous—for the attachment of muscles and ligaments, and

(*b*) Four "articular" processes—two upper and two lower—which in the lumbar region prevent rotation but allow limited flexion and extension between contiguous vertebrae.

Lumbar Vertebra

A lumbar vertebra and its attachments should be studied to obtain a mental picture of the course the needle should take during lumbar puncture. The bone is a massive structure with the following notable features: the spine points almost straight backwards and viewed from the side is square, the vertebral foramen is triangular, the body is kidney shaped. A lumbar vertebra can be

distinguished from any of the lower thoracic vertebrae, the only ones which approach it in size and with which it is likely to be confused, by the absence of articular facets for the ribs.

Each half of the neural arch is divided into two parts by the root of the transverse process. Anteriorly, the arch is formed by the powerful somewhat rounded pedicle or root, part of whose function is to transmit muscular stress; posteriorly it is completed by the thinner, flatter lamina whose function is mainly protective.

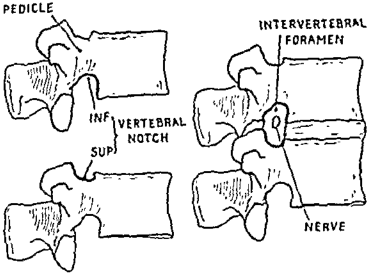


FIG. 5

From the neural arches the four articular processes project, two upwards and two downwards, to articulate with processes on the arches of the two neighbouring vertebrae. The upper ones, like the transverse processes, spring from the junction of pedicles and laminae. They project upwards behind the pedicles and come to lie just above the level of the transverse processes; and the articular facets on their posterior surfaces face backwards and medially. The lower articular processes extend downwards from the infero-lateral aspect of the laminae. They lie well below the level of the transverse processes, and the articular facets on their anterior surfaces face forwards and laterally, so that they accurately oppose the facets on the upper processes of the vertebra below.

The pedicles are noticeably less deep than the body of the vertebra to which they are attached. They arise more from the upper than the lower part of the postero-lateral surface of the body, so that of the two notches formed between body and pedicle the inferior is much the deeper. When two vertebrae articulate, the inferior notch of one vertebra together with the superior notch of the vertebra below it, and the posterior aspect of the intervertebral disc, form a large intervertebral foramen, through which the spinal nerve of that particular segment issues from the vertebral canal. The boundaries of an intervertebral foramen are superiorly and inferiorly the pedicles of adjoining vertebrae, posteriorly the capsule surrounding the articulating processes of adjoining vertebrae, and anteriorly an intervertebral disc and the lower part of the body above it (Fig. 5).

The posterior surface of the body and the neural arch together form the boundaries of the vertebral foramen (Fig. 4, bottom), and in the articulated column these foramina collectively form the vertebral canal which contains the spinal cord and its surrounding membranes.

The anterior boundary of the vertebral canal presents a continuous solid surface being composed of the posterior aspects of the vertebral bodies and intervertebral discs, covered by the posterior longitudinal ligament (Fig. 8). The lateral and the posterior walls, formed by the vertebral arches, however, are incomplete. In the articulated skeleton, it is seen that gaps occur:—

1. Laterally (Fig. 7, A). The formation of the intervertebral foramina in the sides of the column has just been described. Through these run the spinal nerves.

It is quite feasible to give a spinal anaesthetic by means of a needle inserted through an intervertebral foramen. The opening is large, and I have often pierced the theca inadvertently, when attempting paravertebral anaesthesia. However, if one tries deliberately to reach the subarachnoid space by this route, difficulties arise owing to the absence of a good landmark to locate definitely the intervertebral foramen. On this account, this approach is unlikely to oust in popularity the conventional posterior interlaminar approach.

2. Posteriorly (Fig. 7, B). In the lumbar region the gaps are conspicuous, as the depth of the central part of the laminae behind

(Fig. 6, a) is much less than the combined depths of the body and corresponding disc in front (Fig. 6, b).

By taking the spine of the vertebra below as the bony landmark, the situation of an interlaminar foramen can be estimated with considerable accuracy, and advantage is taken of these openings in the bony posterior wall of the vertebral column to perform lumbar puncture.

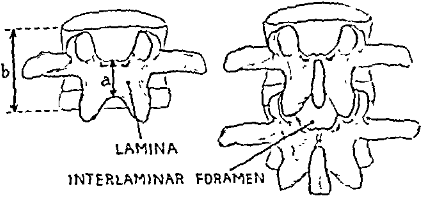


FIG. 6

In the lumbar region an interlaminar foramen is small and triangular in shape when the vertebral column is extended (Fig. 9). The base is formed by the upper borders of the laminae of the lower vertebra, and the sides by the medial aspects of the inferior articular processes of the vertebra above. During flexion the inferior articular processes slide upwards. The interlaminar foramen enlarges and becomes somewhat diamond shaped since now the medial borders of the upper articular processes of the vertebra below form the lower lateral boundaries of the aperture (Fig. 10).

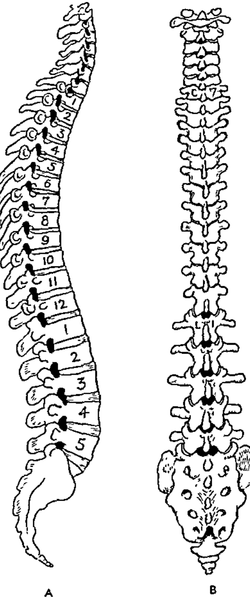
Lumbar Intervertebral Joints

The fact that the vertebrae are separate units gives flexibility to the vertebral column. Although the sum total of movement is considerable and of great practical value to the individual, the movement between any two vertebrae is small, and the articulations are designed more for stability or " backbone."

The joint between the bodies of two vertebrae is fibro-cartilaginous; the union between the arches is ligamentous. The joints between the articular processes are synovial in type. The articular surfaces on the processes effectively prevent rotation, but permit of free gliding movement in flexion and extension.

FIG. 7

The darkened areas represent gaps in the bony vertebral column which encloses the dura and the extradural space. On the left the intervertebral foraminae are seen, and on the right the lumbar interlaminar spaces and the sacral hiatus. The interlaminar gaps between the thoracic vertebrae are concealed from view by the spines of the vertebrae above which overlap the laminae of the vertebrae below like tiles. The five sacral vertebrae are united so that here there are no interlaminar spaces, but failure of the laminae of S.5 to fuse in the midline results in the formation of the sacral hiatus.



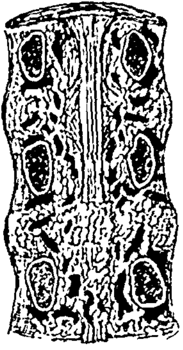


FIG. 8

The pedicles have been cut through, and the vertebral arches, meninges and spinal cord have been removed revealing the continuous anterior surface of the vertebral canal. In the upper part of the central portion the extradural fat and vessels have *been cleared away to show the somewhat* narrow posterior longitudinal ligament which broadens out opposite each intervertebral disc.

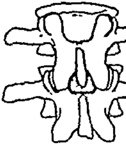


FIG. 9

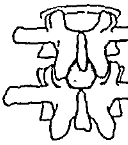


FIG. 10

Bodies

The flat articular surfaces of a vertebral body are covered with hyaline cartilage and this is very firmly united to the fibro-cartilaginous intervertebral discs; and this union between the bodies is reinforced by anterior and posterior longitudinal ligamentous bands, which run the whole length of the vertebral column. The broad anterior longitudinal ligament (Fig. 37) is firmly attached to the intervertebral discs and more loosely to the anterior surfaces of the vertebral bodies. The posterior band (Fig. 8), necessarily narrower since it lies within the vertebral canal,

expands opposite each disc, and is similarly attached to the posterior surfaces of discs and bodies. It sends a few irregular slender fibres to join the anterior surface of the spinal dura mater. In this way the spinal cord is indirectly steadied, yet is little involved in any movement of the vertebral arches during flexion and extension.

Vertebral Arches

The vertebral arches of neighbouring vertebrae are bound together by three ligaments which are of interest to the anaesthetist: —

1. The ligamenta flava, which stretch between the laminae,
2. The interspinous ligaments which join the opposing borders of the spinous processes,
3. The supraspinous ligaments which unite the tips of the spinous processes.

Ligamentum Flavum

This ligament is composed almost entirely of elastic fibres, and as its name implies is yellow in colour. It runs from the anterior and inferior aspects of one lamina to the posterior and superior

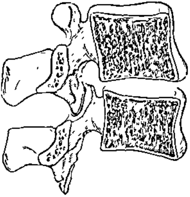


FIG. 11

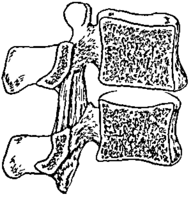


FIG. 12

aspects of the lamina below. Laterally it blends with the capsule of the joint between the articular processes and from here extends backwards and medially to meet its opposite number in the median plane. Just as the two vertebral laminae fuse to form the root of the spine, so the two ligamenta flava meet to become continuous with the deep fibres of the interspinous ligament (Fig. 40).

If the pedicles are cut across and the vertebral arches looked at from within, the ligamenta flava can be seen almost in their entirety (Fig. 37). They cover the capsules of the articular facets, the lower part of the upper laminae, and the interlaminar spaces.

From behind, the ligamenta flava cannot be seen at all throughout most of the thoracic region: for here the laminae and oblique spines, like overlapping tiles, effectively obscure the vertebral canal. In the lumbar region, however, the ligaments become apparent because of the shallowness of the laminae and the horizontal direction of the spines. But even here the ligaments are seen only where they fill the interlaminar spaces and where their lower attachments conceal a small amount of the upper part of the succeeding laminae. Whether viewed from in front or behind, then, part of the ligament is always hidden from view, whilst the portion of the ligament occupying the interlaminar gap is seen from both aspects.

The ligamenta flava constitute slightly more than half of the posterior wall of the vertebral canal. They are thickest and strongest in the lumbar region where powerful stresses and strains have to be countered. They act as muscle sparers in maintaining erect posture; they help to regulate flexion so as to prevent injury to the intervertebral discs, and they help to restore the body to the erect position after it has been flexed. In the dissections from which figures 76 to 80 were drawn, the vertebrae were in extension; the ligamenta flava are therefore shown thicker than when encountered during lumbar puncture in life with the back well flexed and the ligaments stretched. Nevertheless, the ligamentum flavum is thicker than commonly imagined.

One often sees the anaesthetist correctly recognise the ligament by touch as the needle penetrates its dorsal aspect. As he pushes on through the thick ligament, another sudden alteration in resistance is sometimes encountered as the needle passes through the deep surface into the extradural space; and this slight jolt is often incorrectly interpreted as penetration of the dura mater. This double alteration in resistance together with absence of flow of cerebro-spinal fluid locates the point of the needle in the extradural space.

It is clear that a needle piercing the ligament at its lower margin may be prevented from reaching the theca by the upper edge of the lamina to which the ligament is attached. This point

is of importance in helping the anaesthetist to visualise the state of affairs when he has sensed that the needle has penetrated the ligamentum flavum and is immediately afterwards held up by bone. (See Figs. 39 and 80.)

Interspinous Ligament

This is a thin ligament, the fibres of which are attached along

FIG. 13
The ligamentum flavum (*a*) and the interspinous (*b*) and supraspinous (*c*) ligaments.

the lengths of the spinous processes, uniting the lower border of one with the upper border of its caudad neighbour; in the lumbar region therefore the ligament is rectangular in shape (Fig. 13). Anteriorly, at the level where the spines are formed by the fusion of the laminae, the interspinous ligament blends with the ligamenta flava; posteriorly the interspinous fibres are continuous with those of the supraspinous ligament.

Supraspinous Ligament

The fibres of this tough ligament unite the apices of the spines of the lumbar and thoracic vertebrae and continue above as the ligamentum nuchae. The ligament may be almost half an inch wide in the lumbar region to correspond with the spines which are broadest in this situation. In labourers and in old age, ossification from the spine may extend along the fibres of this tough ligament; the space then available in the median plane between two spines for the passage of a lumbar puncture needle is therefore less than a study of the dry bones would suggest. In fact in these cases it may be almost impossible to insert a needle in the median plane, but a needle inserted just lateral to the supraspinous ligament can be directed to the interlaminar space without meeting obstruction.

The Intervertebral Disc

The intervertebral discs form at least one quarter of the total length of the vertebral column. In certain regions they are somewhat wedge-shaped and thus contribute to the characteristic curves of the column. The discs are thickest in the lumbar region where weight bearing is maximal, and movement, except rotation, is considerable.

Each disc consists of a fibrous outer cover, the annulus fibrosus, which is attached to the hyaline cartilage covering the articular surfaces of the two vertebral bodies it connects. The annulus encloses a core of gelatinous material, the nucleus pulposus, which accommodates itself to the changes in shape of its covering during movement between the vertebrae. Intervertebral discs thus act as shock absorbers and give flexibility to the vertebral column.

As a result of weakness or strain the annulus may rupture, usually posteriorly where it is thinnest. The nucleus pulposus may then herniate through the deficiency, causing symptoms and signs which depend on the nerve or nerves involved. Protrusion of the nucleus pulposus—a "prolapsed disc"—has been described following lumbar puncture, and it must be borne in mind that careless technique may be a contributing factor. The mechanics of such an injury are easy to visualise. The nucleus pulposus, through which passes the axis of flexion or extension of one vertebra on another, is situated somewhat posteriorly in the disc. The nucleus pulposus draws its fluid content from the spongiosa of the adjacent vertebrae by *osmosis*[3] and even in normal circumstances is under considerable

pressure. When the lumbar vertebrae are fully flexed, as during lumbar puncture, the nucleus pulposus is squeezed backwards, greatly increasing the strain on the annulus posteriorly where it is weakest. If, in these circumstances, a needle is inadvertently

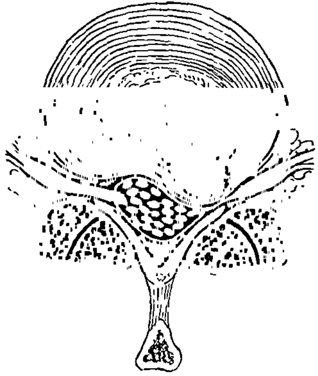


FIG. 14

Protrusion of the nucleus pulposus. After Naffziger and Boldrey.[2] This disability has been reported frequently following lumbar puncture. On the right-hand side the nerve roots for that segment are compressed against the ligamentum flavum and articular processes.

pushed through the subarachnoid space and the annulus is pierced, a prolapsed disc may be precipitated; and this accident is more likely to happen if the needle is blocked so that cerebro-spinal fluid cannot issue when the tip is correctly placed.

Meninges

The names of the enveloping meninges or membranes of the central nervous system are self-descriptive. The dura mater is tough, the arachnoid cobweb-like, and the pia mater tender and clinging.

Dura Mater

The dura mater, although continuous, can be described in two parts, cranial and spinal. The cranial dura consists of two layers, endosteal and meningeal, closely united except where they enclose

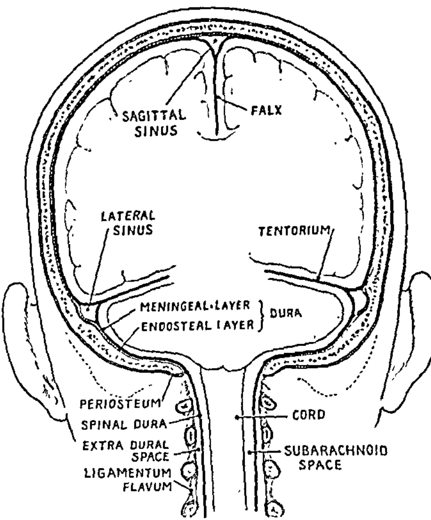


FIG. 15
See also Fig. 17.

the great venous sinuses which drain the blood from the brain (Fig. 15). At the foramen magnum the endosteal layer which lines the skull becomes continuous with the periosteum on the outer surface of the bone. The meningeal layer invests the brain and folds inwards to form the tentorium cerebelli and falx cerebri which divide

the cranial cavity into freely communicating compartments, and being taut "prevent shifting of the cranial cargo." [4]

The outer or endosteal layer of the cranial dura mater is represented in the vertebral canal by the lining periosteum.

The spinal dura mater or theca, the loose outermost and by far the toughest of the three sheaths surrounding the spinal cord, is the continuation downwards of the inner or meningeal layer of the cranial dura mater. Above, it is firmly attached to the circumference of the foramen magnum of the occipital bone. Below, the dural enclosure ends at the lower border of the second sacral vertebra (Fig. 17), where it is pierced by the filum terminale, the terminal thread of pia mater which runs from the end of the spinal cord to blend with the periosteum on the back of the coccyx. The filum terminale anchors cord and theca and the latter is further steadied, particularly in the lower end of the vertebral canal, by fibres from the posterior longitudinal ligament.

Arachnoid Mater

The arachnoid is the middle of the three coverings of the brain and spinal cord. It is a delicate non-vascular membrane closely applied to the dura mater, and with it ends at the lower border of the second sacral vertebra. There is a capillary interval, the subdural space, between the dura and the arachnoid. It contains a minute quantity of serous fluid but has no connection with the subarachnoid space which contains the cerebro-spinal fluid. The dura and arachnoid are in such close contact that in the process of lumbar puncture it is not possible to pierce the dura without piercing its companion membrane. On this account, in describing the technique, it is common to omit any reference to the arachnoid; and in fact the subarachnoid space is sometimes loosely, though incorrectly, referred to as the subdural space.

Pia Mater

The pia mater is a delicate, highly vascular membrane closely investing the cord and brain, clinging to the surface of the latter throughout its irregular contours.

Extradural Space

The extradural (peridural, epidural) space is that part of the vertebral canal not occupied by the dura mater and its contents. It lies between the dura and the periosteum lining the canal, and

corresponds to the very restricted space within the skull between the two layers of the cranial dura mater enclosing the venous sinuses (Fig. 15).

The extradural space extends from the sacral hiatus to the base of the skull. Except in the lower sacral region it is annular in shape, and narrow. The anterior and posterior nerve roots in their dural coverings pass across the very narrow space to unite in the intervertebral foramen to form the segmental nerves. The rest of the extradural space is occupied by numerous small veins and by fatty areolar tissue which is continuous around the nerves through the intervertebral foramina with the fat in the paravertebral spaces. The extradural space and its communications can be outlined easily by the instructive exercise of injecting a liberal quantity of methylene blue through the sacral hiatus of a cadaver. A varying amount runs out around the nerves through the various sacral foramina, and through the lumbar, thoracic and cervical intervertebral foramina, but the upward spread is limited by the attachment of the dura to the circumference of the foramen magnum. The sciatic nerves will be found to be stained for a considerable distance into the thighs, and if the thorax is opened a blob of blue is found in practically every thoracic paravertebral space between the heads of adjoining ribs. Here the dye has seeped out from the extradural space, through the foramina, and extends along the intercostal spaces for varying distances; but this staining is not uniform, since occasionally some of the intervertebral foramina are partially occluded by fibrous tissue.

The experiment explains two things. Firstly, the unpredictability of the spread of a limited quantity of anaesthetic solution in the extradural space, on account of the numerous openings through which the fluid can escape, and secondly, the reason for the well recognised phenomenon of the negative pressure in certain parts of the space. The paravertebral spaces between the heads of the ribs are virtually intrathoracic and subject to the variations in intrathoracic pressure. The fat in these spaces communicates freely, around the intercostal nerves, with the fat in the extradural space (Fig. 16). The negative intrathoracic pressure is therefore transmitted to some extent to the extradural space in the thoracic region; but this negative pressure diminishes as one passes up or down the vertebral column away from the thorax.[4]

In lumbar puncture the needle must pass through the extradural space. Although not necessary it is not unprofitable to determine when the point of the needle lies within the space on its way to the dura. One way of doing this is illustrated on page 86.

Some anaesthetists are keen advocates of extradural analgesia, as opposed to intradural, *i.e.*, spinal. Their aim here is to anaesthetise, by spread of local anaesthetic solution, the nerve roots in their very short course across the extradural space to their intervertebral foramina.

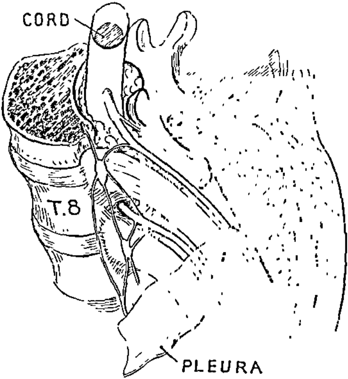


FIG. 16
The extradural space. The fat has been removed from the 8th intervertebral foramen. (*After Macintosh and Mushin.*[5])

As in other parts of the body, the amount of fat in the areolar tissue of the space depends on the obesity of the subject; but in any case it is greatest in the median plane posteriorly where the summit of the vertebral arch is commonly separated from the rounded posterior aspect of the dura by approximately one-third

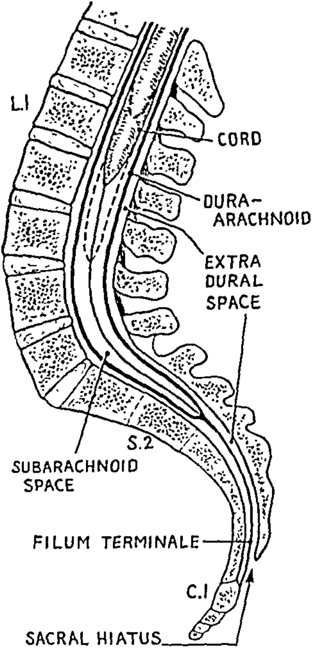


FIG. 17

In the adult male the spinal cord is 18 inches long. It is generally stated to end at the lower border of the 1st lumbar vertebra, but Reimann and Anson[6] found this to be so in only 50 per cent. of 129 adults examined by them. In 121 of these cases (94 per cent.) the cord ended opposite either the 1st or the 2nd lumbar vertebra: of the remainder, five finished opposite the 12th thoracic, and three as low as the 3rd lumbar vertebra. Compare with Fig. 15.

inch, and antero-laterally where it is continuous with the pads of fat surrounding the spinal nerves in the intervertebral foramina. Between the postero-lateral walls of the lumbar vertebral canal and the dura, the space is narrower, and the fat less evident. Anteriorly, in a thin subject, the space is only potential, since here the dura lies close to the posterior longitudinal ligament on the posterior aspects of the vertebral bodies.

The extradural space extends from the foramen magnum to the sacral hiatus, the dural sac from the foramen magnum to the lower border of S.2. The anaesthetist takes advantage of this discrepancy in caudal analgesia, when he introduces a needle through the sacral hiatus into the caudal part of the sacral canal,—the lowermost part of the extradural space—without piercing the dura. The spread of the local anaesthetic solution injected into the extradural space is not accurately predictable, because of the resistance offered by the fatty areolar tissue and because of the numerous foramina through which the fluid can leak; but it is reliable enough to make extradural analgesia a practical method of providing pain relief.

Subarachnoid Space

The subarachnoid space is lined externally by the arachnoid, internally by the pia mater, and innumerable cobweb-like

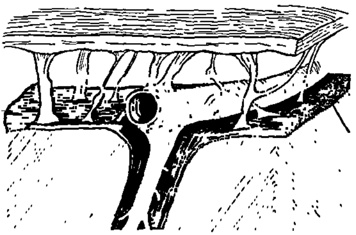


FIG 18
From Kuntz,[7] after Weed Delicate strands of arachnoid tissue cross the narrow subarachnoid space to be attached to the pia

trabeculae run between the two membranes, though sparsely in the cisterns. It is traversed by the cranial and spinal nerves. It houses the main blood vessels of the central nervous system, and extends

FIG. 19
Section through the 12th thoracic segment of the cord at the level of the 9th thoracic vertebra. The anterior and posterior roots of the 10th, 11th and 12th thoracic nerves are seen. (*After Ranson.*[5])

along the smaller arteries and capillaries into the nervous tissue of the brain and spinal cord (Fig. 18): here the cerebro-spinal fluid takes the place of the tissue fluid (lymph) found in other regions of the body—vide p. 38. In the cervical and thoracic regions the space is annular and the distance between the arach-

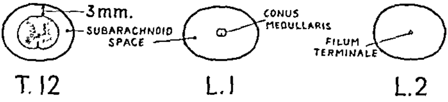


FIG. 20

noid and the pia covering the cord, even in an adult, is only about 3 mm. (Fig. 20), so that a spinal tap here is fraught with the danger of injuring the cord with the needle. The cord commonly finishes at the lower border of the first lumbar vertebra so that below this level the subarachnoid space is no longer annular but is

practically circular in section (Fig. 36) and has a diameter of about 15 mm. Lumbar puncture should be carried out in the lower lumbar region. As will be seen later, the approach of the needle to the subarachnoid space here is easy. The fact that the cord terminates above this level renders it immune from injury, the constituent nerve roots of the cauda equina escape damage on account of their relative mobility, and the absence of the cord greatly increases the cross sectional area of the subarachnoid space, the ultimate target at which the needle is aiming.

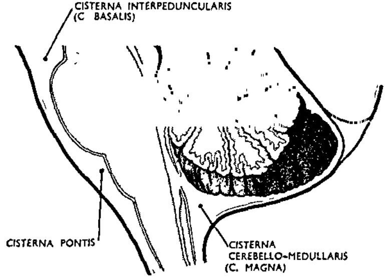


FIG. 21

In the skull the pia and arachnoid membranes are, for the most part, in fairly close apposition, especially at the summit of the cerebral convolutions, but since the pia closely follows the irregularities of the brain surface and dips into sulci which are bridged by the arachnoid a large number of gaps occur between the two membranes which are filled with cerebro-spinal fluid. In certain situations, such as the base of the brain, these spaces are of considerable size, and are referred to as *cisterns*. Examples of these are the cisterna magna formed where the arachnoid does not follow the pia closely into the angle between the medulla and undersurface of the cerebellum (Fig. 21), and the cisterna pontis which is a wide space on the ventral aspect of the pons.

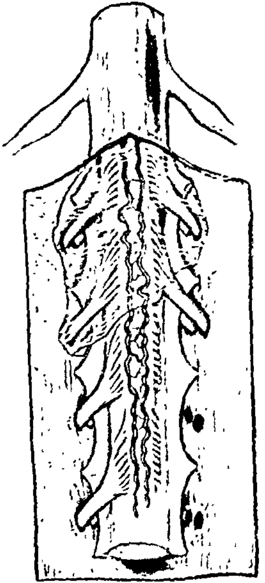


FIG. 22

The dura has been opened to show the dentate ligaments and the posterior aspect of the cord in the upper thoracic region. In the middle of the picture the flimsy arachnoid can be seen. On the lower right-hand side the anterior and posterior nerve roots have been removed showing the points where they pierce the dura separately, but closely associated.

Ligamenta Denticulata

The two ligamenta denticulata are so named because of their resemblance to the teeth of a saw. They consist of two serrated folds of the pia which surrounds the cord, and they project at right angles in the mid-lateral line from the cord to the dura. The bases of the ligaments extend continuously from the bulb almost to the conus medullaris, that is along practically the whole length of the cord, separating the anterior from the posterior nerve roots (Fig. 22). From the bases, twenty-one pairs of teeth, corresponding in number to the cervical, thoracic and first lumbar nerves, project on either side, and the apices of the teeth are attached to the inner surface of the dural sac at points midway between the exits of successive spinal nerves. The lowest tooth of the ligament curves downwards and is crossed in front and behind by the roots of the first lumbar nerve (Fig. 35). The ligaments support the cord, and anchor it fairly firmly in the centre of the dural sac.

Posterior Subarachnoid Septum

The cord is further steadied and the subarachnoid space again subdivided by the posterior subarachnoid septum. The fine strands of this incomplete and inconstant partition pass from the midline of the dorsal surface of the cord directly backwards to be attached to the arachnoid.

Neither the denticulate ligament nor the subarachnoid septum exercise any detectable influence on the spread of local anaesthetic injected into the subarachnoid space.

Cauda Equina

In early foetal life the cord is as long as the vertebral canal. During development, however, increase in length of the cord does not keep pace with the growth of the vertebrae, so that soon a great disproportion results between the length of the bony column and the spinal cord it protects. At birth the tip of the cord has risen from the level of the 2nd coccygeal vertebra to the lower border of the 3rd lumbar vertebra, a distance of nine segments. After birth the growth in length of the cord still lags behind that of its bony enclosure, but the difference is less marked so that by the time the growth ceases, the end of the cord has risen generally by another two segments to the lower border of the 1st lumbar vertebra.

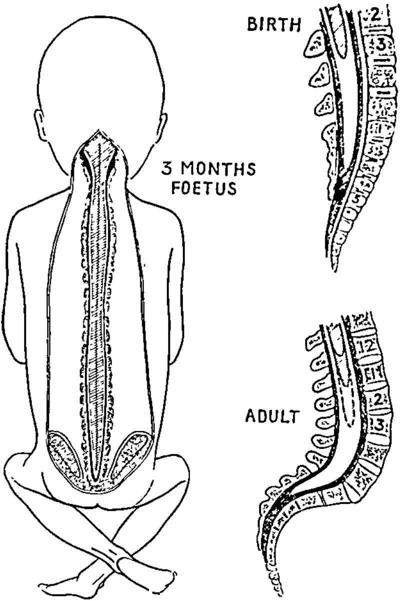


FIG. 23

If growth of the cord had kept pace with that of the vertebrae the nerve roots would run transversely from the cord to their corresponding intervertebral foramina. This happens in the cervical region, but because of the relative inequality in the rate of growth of bony column and cord, the thoracic nerve roots run an increasingly oblique course; and the direction of the lower lumbar and sacral roots is practically vertical. Since the latter roots are necessarily given off before the spinal cord ends at the level of say the 1st lumbar vertebra, most of them must perforce run almost vertically downwards for several inches behind the bodies of the remaining four lumbar vertebrae before passing through the dura to reach their corresponding lumbar and sacral foramina. The 1st lumbar nerve has the highest and most lateral point of origin from the conus medullaris. The 2nd lumbar nerve arises immediately below this: and the sequence continues until the lowest sacral and the coccygeal nerve roots leave the tip of the conus and so occupy the central part of the subarachnoid space (Fig. 35). The general appearance of the nerve roots in this region readily suggests the description of cauda equina or horse's tail.

The nerve roots here are completely immersed in cerebro-spinal fluid, and since they enjoy a considerable range of mobility, they are immune from injury during straightforward lumbar puncture. No doubt they are frequently touched by the invading needle, but they float easily to one side and escape damage in the same way as the elusive apple does when being "bobbed" for in a bucket of water.

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CHAPTER III

Cerebro-Spinal Fluid

Source

THE cerebro-spinal fluid is derived from the choroid plexuses which are formed in all four ventricles of the brain by the invagination of vessels from the subarachnoid space. These vascular protrusions, supported in a matrix of pia, are thrown into many folds which carry on their surfaces a great number of minute lobulated tufts into each of which afferent and efferent

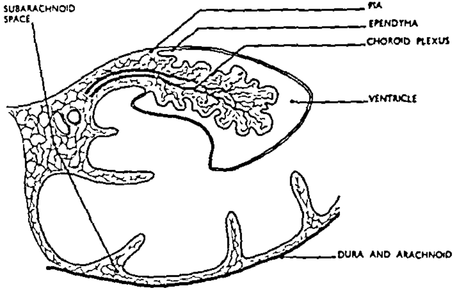


FIG. 24

vessels may be traced; the capillaries are in intimate contact with the ependyma, the single layered epithelium lining the ventricle.

Method of Formation

Two theories have been advanced to explain the method of formation of the cerebro-spinal fluid. The first, that the extremely thin layers of pia and ependyma intervening between the capillaries and the ventricles act solely as a simple dialysing membrane, is untenable because of the differences in concentration of certain natural solutes in blood and cerebro-spinal fluid,[1] and because of

the hold-up at the blood-cerebro-spinal fluid barrier of both toxic and therapeutic agents which normally would pass through an ordinary colloid membrane.[2] The second theory holds that besides permitting selective filtration the cells of the ependyma have a secretory function. It is true that no new solution such as mucin, bile or milk is elaborated, but it is held that the production of cerebro-spinal fluid is effected by active secretion on the part of the

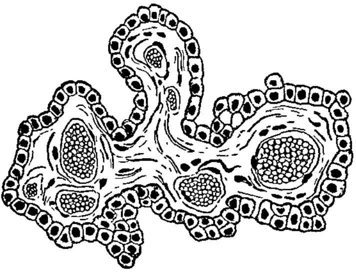


FIG. 25
Section of a villus of the choroid plexus. (*After Maximov and Bloom.*[3])

ependymal cells.[2] The secretion theory is strengthened by the vacuolation which is seen when the cells are examined microscopically.

The present uncertainty which prevails about the method of its formation is made evident in some quarters by referring to cerebro-spinal fluid somewhat vaguely as a "selective transudate."

Circulation

The cerebro-spinal fluid circulates slowly. The bulk is formed in the lateral ventricles and passes through the interventricular foramina (of Monro) to mix with the fluid produced in the third ventricle. From here it passes along the aqueduct of Sylvius to the

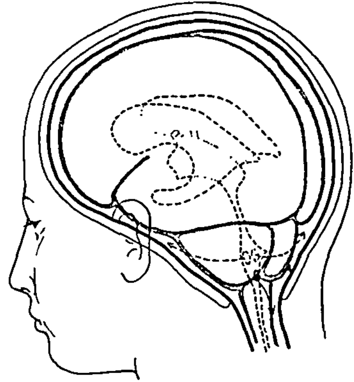
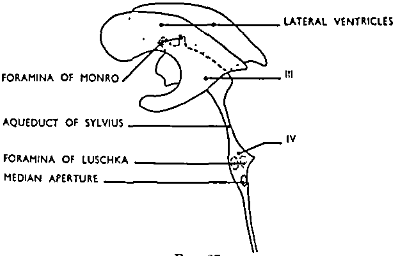


FIG 26



LATERAL VENTRICLES
FORAMINA OF MONRO
III
AQUEDUCT OF SYLVIUS
IV
FORAMINA OF LUSCHKA
MEDIAN APERTURE

FIG. 27

fourth ventricle, and reaches the subarachnoid space by flowing through the three openings in the roof of this ventricle; the two foramina of the lateral recesses (Luschka) lead forward from either side to the region of the cisterna pontis, and the median aperture (of Magendie) drains backwards into the cerebello-medullary cistern. These cisterns at the base of the brain communicate freely with the spinal subarachnoid space, but the main circulation of fluid continues in the cerebral subarachnoid space upwards through the opening in the tentorium cerebelli, and then over the cerebral

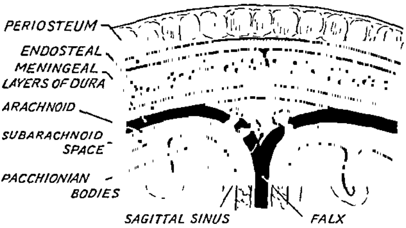


FIG. 28

hemispheres. The cerebro-spinal fluid passes back into the blood stream by filtration and osmosis. Transference takes place chiefly in the supratentorial region, through arachnoid villi and granulations, Pacchionian bodies (Fig. 28), formed where the arachnoid bulges into and penetrates the meningeal dura to come into direct contact with the endothelium of the great venous sinuses.

Some authorities[4] hold that there is no active circulation of cerebro-spinal fluid in the spinal subarachnoid space but that osmosis, alterations in posture, and arterial pulsations tend to keep the composition of the fluid constant. Others believe that there is a slow circulation downwards and that fluid passes directly into venous plexuses in the spinal subarachnoid space,[5,6] and that some leaves the dural sac along the course of the segmental nerves to be absorbed by the lymphatics.[7]

There is no suggestion that any circulation of cerebro-spinal fluid there may be in the spinal subarachnoid space influences the distribution of analgesic solutions injected there. Moreover, in the rare event of an analgesic solution reaching as high as the foramen

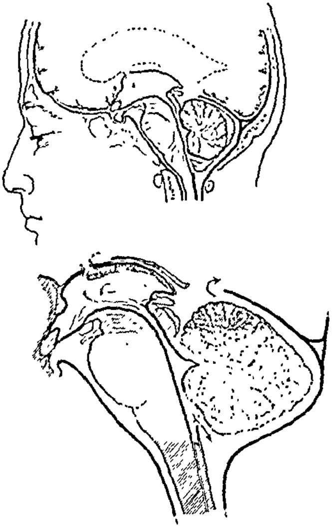


Fig. 29

magnum, it is more easy for it to spread in the cerebral subarachnoid space anaesthetising the cranial nerves as they pass across it, than it is for the solution to enter the foramina of Luschka and Magendie "against the stream" and gain access to the respiratory and cardiac centres situated in the floor of the fourth ventricle.

Composition

The cerebro-spinal fluid is clear, colourless, and does not clot on standing. It has the same pH as serum, 7·4, so that it is just alkaline. The specific gravity of the fluid at body temperature, referred to water at 4°C., is 1·0003 (p. 117). The protein content, 20-30 mg. per 100 cc., is very low, and the antibody value is correspondingly poor. The glucose content of 45-80 mg. per 100 cc. is also low, and the high chloride content of 720-750 mg. per 100 cc. is the main factor in keeping the cerebro-spinal fluid in osmotic equilibrium with the plasma. In normal health the cells present in the cerebro-spinal fluid are almost entirely lymphocytes and their number does not exceed 5 per c.mm.

Functions

The cerebro-spinal fluid does not contain any substances not found in the blood; this lends colour to the idea that its purpose is mainly a physical one. By acting as a mechanical buffer the fluid absorbs and distributes the force of a blow on the head, thus affording considerable protection to the brain and cord. The deep collections of fluid in the cisternae around the base of the brain serve *admirably as a water cushion. The fluid here floats the brain.* As Livingstone points out,[3] "The comparative densities of cerebro-spinal fluid and nervous tissue are such that a brain and spinal cord weighing about 1,500 grams when removed from the cranio-spinal chambers would have a net weight *in situ* of less than 50 grams." The cerebro-spinal fluid is also a compensatory mechanism whereby the pressures in the cranial and spinal cavities are equalised and kept within physiological limits.

There is no evidence of the presence of lymphatics anywhere throughout the central nervous system; the removal of waste products arising from the activity of the nerve cells, therefore, must be effected by some other means. As an artery penetrates the brain substance, it carries with it a thin layer of pia (Fig. 18), and the potential perivascular space is thus continuous with the subarachnoid space. Because of this continuity it is reasonable to suppose that the cerebro-spinal fluid plays an important role as scavenger for the central nervous system, a part played elsewhere in the body by lymph.

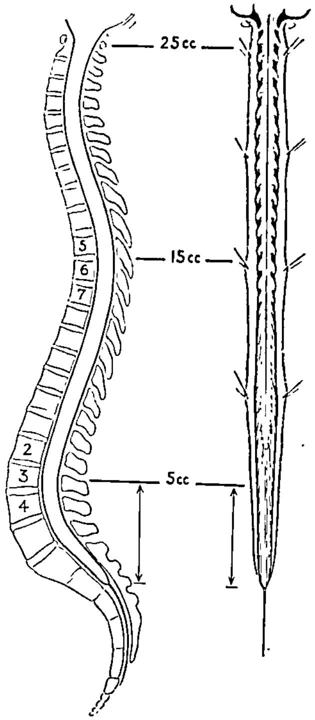


FIG. 30

Volume

Estimates of the total volume of cerebro-spinal fluid in an adult vary between 100-150 cc. More important to the anaesthetist is the volume of cerebro-spinal fluid in the spinal subarachnoid space. Here, too, estimates show considerable variation,[9] but figure 30 gives reasonable approximations. There are two tips which help to memorise the volume of cerebro-spinal fluid at different levels. The dural sac ends at the lower border of S.2, and 1 cc. of cerebro-spinal fluid should be reckoned for every vertebral level above this. The volume of fluid at the mid-lumbar vertebra is about 5 cc., at the mid thoracic region 15 cc., and at the foramen magnum 25 cc.

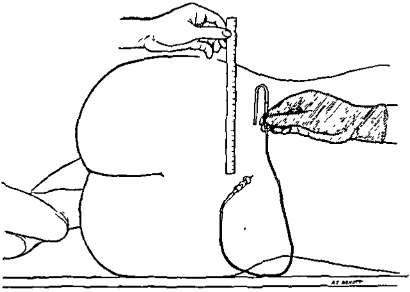


FIG. 31

Pressure

There are small rhythmic fluctuations in the pressure of the cerebro-spinal fluid These fluctuations, readily seen on a manometer attached to a lumbar puncture needle, are related to cardiac impulse and respiration and may play their part in circulation and absorption of the fluid.

When the patient sits up, the column of cerebro-spinal fluid bulges the spinal theca into the loosely filled extradural space. The pressures in the ventricles, and even in the basal cisterns, are now

slightly below atmospheric so that a ventricular or cisternal puncture will not yield fluid except on suction. The pressure within the theca depends almost entirely on the hydrostatic pressure of the fluid above the level at which the needle is inserted. For this reason readings taken with the patient in the sitting position give no indication of the real cerebro-spinal fluid pressure. This can be measured only when the patient is horizontal (Fig. 31). Then the pressures in the ventricles, cisternae and lumbar sac, are equal. Normally the figure lies within the range of 70-170 mm. water.

One of the functions of cerebro-spinal fluid is to stabilise the pressure within the skull. Since the walls are rigid, any change in volume of one of the contents, brain, blood or cerebro-spinal fluid must be compensated for by a change in the opposite direction in the others. The blood volume of the brain fluctuates according to physiological requirements, and any increase must be accompanied by a decrease in the volume of cerebro-spinal fluid: otherwise the brain will be compressed. The pressure of the fluid rises and this in turn accelerates the rate of its absorption.

The principal factors which influence the pressure of cerebro-spinal fluid are:—

(i) *Anything which alters the cerebral venous pressure.* Thus cerebral venous engorgement due to congestive heart failure may give a cerebro-spinal fluid pressure reading up to 500 mm. of water.[10] Respiratory obstruction from any cause, by interfering with the venous return to the thoracic cavity, has a similar effect.

An immediate transient rise in cerebro-spinal fluid pressure is caused, too, by sudden increase of cerebral venous pressure from coughing, or by deliberately obstructing the internal jugular veins. (Queckenstedt's test.)

(ii) *The tension of CO_2 in the blood.* Any increase whether derived from adding this gas to the inspired mixture, or from deficient elimination due to respiratory depression following the administration of morphine or the barbiturates, enlarges the cerebral vascular volume, causing a marked rise in cerebro-spinal fluid pressure.

(iii) *Infection or irritation of the meninges.* Quite apart from overt infection, an appreciable rise of cerebro-spinal fluid pressure is on occasions seen after simple lumbar puncture or after a spinal anaesthetic. The cause is sometimes ascribed to "aseptic chemical meningitis."

(iv) *Changes in osmotic pressure of the blood.* These affect both the formation and absorption of cerebro-spinal fluid. If the osmotic pressure of the blood is lowered directly by an intravenous injection of a hypotonic solution the cerebro-spinal fluid pressure rises.

If pitressin is administered, water elimination from the kidneys is decreased. If water is now ingested, a decrease in osmotic pressure results from the retention of the fluid; the cerebro-spinal fluid pressure rises. Similarly, if insulin is given slowly, the blood sugar content is lowered, and the cerebro-spinal fluid pressure rises.

An intravenous injection of hypertonic solution of sodium chloride, glucose, or magnesium sulphate, causes the cerebro-spinal fluid pressure to drop. By the same token the pressure of cerebro-spinal fluid is low in a patient who for any reason is dehydrated.

(v) *Leakage of cerebro-spinal fluid.* Headache is a common sequel to lumbar puncture and many attribute this to low pressure of cerebro-spinal fluid due to leakage through the dural puncture (p. 126). A second lumbar puncture carried out in these circumstances to test for infection may reveal an exceptionally low pressure of cerebro-spinal fluid.

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[2] Voetmann, E. (1949) *Acta anat.* 8, suppl. 10, 1-116; cf. pp. 17-18
[3] Maximov, A. A. and Bloom, W. (1952). *A textbook of histology*, 6th ed. p 201. Philad.
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[illegible] *cerebrospinal fluid*, p. 47. Philad.

CHAPTER IV

Illustrations

FIG. 32
Suggested by a drawing by Mr. L. Schlossberg, by courtesy of Dr. R. A. Hingson.

FIG 32

The second lumbar vertebra has been cut through vertically, close to the median plane. The left pedicle and lamina of the 3rd vertebra have been cut through and the intervening piece, which includes the superior articular and transverse processes, has been removed. See inset.

FIG 33

Articulated vertebral column. Interlaminar foramina are seen between T.12-L.1, all the lumbar vertebrae, and L.5-S.1, offering approaches to the extradural space and dura mater.

The triangular sacral hiatus is formed by failure of the laminae of the 5th sacral vertebra to fuse. A needle inserted through the tough, taut, fibrous membrane covering the hiatus at once enters the extradural space. Owing to the curvature of the sacrum and to the fact that the dural sac terminates some distance above—*opposite the lower border of the 2nd sacral vertebra (Figs. 17, 34)*—this approach is never made deliberately to the subarachnoid space. Nevertheless, inadvertent puncture of the dura occurs from time to time when caudal extradural analgesia is intended, and if this accident is not detected early it may well provide alarming complications, for the large volume of solution necessary for caudal extradural analgesia would then be injected intradurally.

FIG. 34

The extradural space has been exposed by removing the laminae of the sacral vertebrae, and by cutting through the pedicles and taking away the vertebral arches of the lumbar and thoracic vertebrae. The extradural fat has been cleared away.

The extradural space is continuous from the sacral hiatus to the foramen magnum and communicates with the paravertebral spaces through the intervertebral foramina. Spread of any given quantity of fluid injected into the extradural space is not accurately predictable because of the resistance offered by the loose areolar tissue which occupies it, and because of escape through the numerous intervertebral foramina.

The lower limit of the theca is seen opposite the lower border of S.2, and the 3rd, 4th and 5th sacral nerves, the coccygeal nerve and the filum terminale are shown emerging from it and descending in the caudal part of the sacral canal.

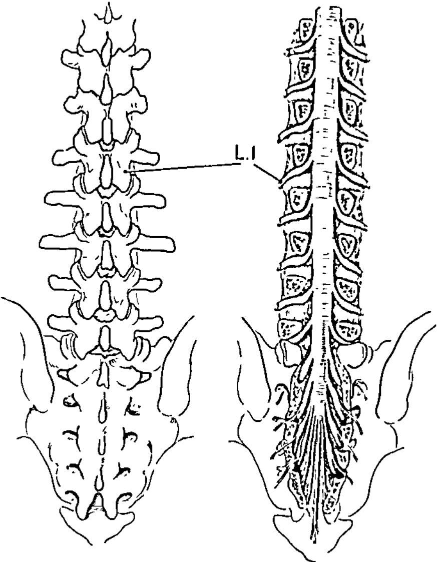
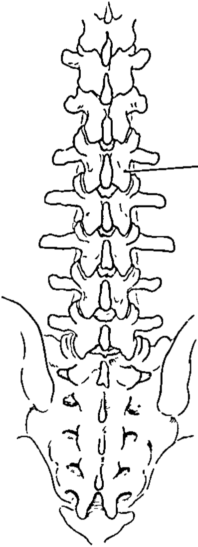


FIG. 33

FIG. 34

Compare with Figs. 35 and 36.



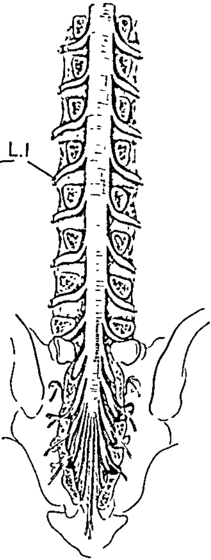


Fig. 33

Fig. 34

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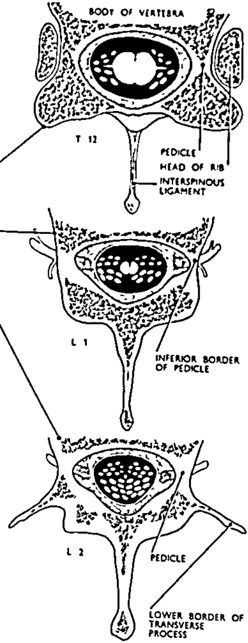

FIG. 35

FIG. 36

Compare with Figs. 33 and 34.

FIG. 35

The dura mater and arachnoid have been opened, showing the cord ending at the lower border of L.1. The filum terminale, pulled aside in its upper course, continues, leaving the subarachnoid space at its extremity; from here it passes through the sacral canal, and out of the sacral hiatus, to be anchored to the posterior surface of the body of the 1st segment of the coccyx.

On the right the nerve roots, except for L.1, have been removed in their subarachnoid course; the holes for their escape through the arachnoid-dura are seen.

The ligamenta denticulata (p. 29) end just above the lower end of the spinal cord, and the bases of the lower serrations separate the anterior and posterior roots of several lumbar nerves as they pass vertically downwards to their exits. The lowest denticulation, recognised by its obliquity, serves as a guide for the neurosurgeon to the roots of L.1, which pierce the dura just below it.

In this specimen the dural sac ends very slightly higher than usual. When attempting caudal extradural analgesia, the anaesthetist must bear in mind the possibility that the sac may terminate abnormally low and be penetrated by the needle inserted through the sacral hiatus.

FIG 36

Top. Section through T.12. (See corresponding arrow, Fig. 35.) A lumbar puncture at this level might injure the cord. The bases of the dentate ligaments are seen separating the fibres of the anterior and posterior roots of four lumbar nerves on either side.

Middle. Section through L.1. The conus medullaris can be injured by lumbar puncture at this level. The dentate ligament has ended. The nerve roots within the dura are L.2-5, which have taken origin higher up, and S.1-2 which have just left the conus.

Bottom. Section through L.2. (See corresponding arrow, Fig. 35.)

Lumbar puncture carried out below this level is reasonably free from the danger of injuring the cord which usually terminates at L.1. The theca contains at this level the individual lumbar and sacral nerve roots, each of which, cushioned by cerebro-spinal fluid, enjoys considerable mobility as it runs downwards from the cord to its exit from the dura. The descending nerve roots do not pierce

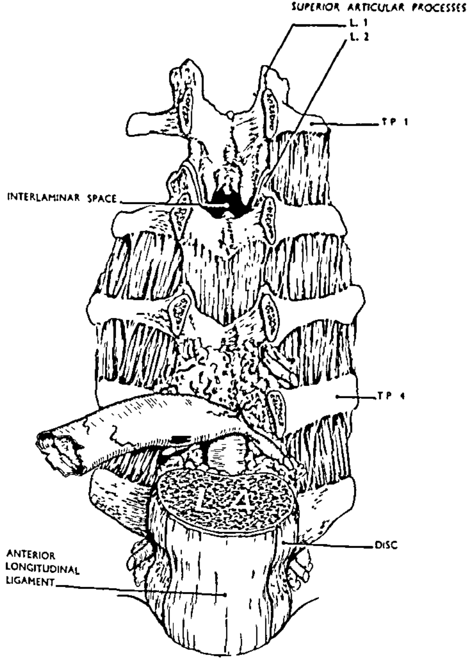
SUPERIOR ARTICULAR PROCESSES
L. 1
L. 2
T P 1
INTERLAMINAR SPACE
T P 4
DISC
ANTERIOR
LONGITUDINAL
LIGAMENT

FIG 37

the dura and unite to form the nerve trunk until they reach the level of their particular intervertebral foramen.

The 2nd lumbar nerve has left the dura immediately below this section, and is seen passing through the extradural space to reach the intervertebral foramen just below the border of the pedicle. Outside the dura the nerve is relatively fixed and therefore much more likely to give rise to pain if encountered by the lumbar puncture needle well out of its course. Pain down the thigh is a sure sign that the needle has penetrated the ligamentum flavum and is deep enough for dural puncture, although it has passed too much to one side. All the anaesthetist has to do is to withdraw the needle slightly and reinsert it to the same depth directing the point a little away from the side on which the pain was felt. See figure 73.

FIG. 37

The bodies of L.1, 2, 3 and most of 4 have been removed by sawing through the pedicles, and across the lower border of the body of L.4. The roots of the 4th lumbar nerve in their dural coverings run across the extradural space, and the nerve is seen leaving the intervertebral foramen. In the 3rd lumbar interspace, the extradural fat and vessels have been left intact. The left 3rd lumbar nerve, cut from its dural attachment, is seen leaving the intervertebral foramen immediately in front of the lateral margin of the ligamentum flavum, which can be discerned through the fat.

In the space above, the fat and vessels have been cleared away to show the posterior boundaries of the extradural space—the ventral aspect of the upper halves of the laminae and the ligamenta flava.

In the uppermost space, the ligamenta flava and the capsules surrounding the articular facets have been removed. Even allowing for the fact that the specimen is in the extended cadaveric position, the interlaminar foramen is much smaller than visualised before the ligamenta flava are removed. When the spine is flexed the inferior articular facets of one vertebra ride up on the superior facets of the vertebra below, considerably increasing the size of the interlaminar space.

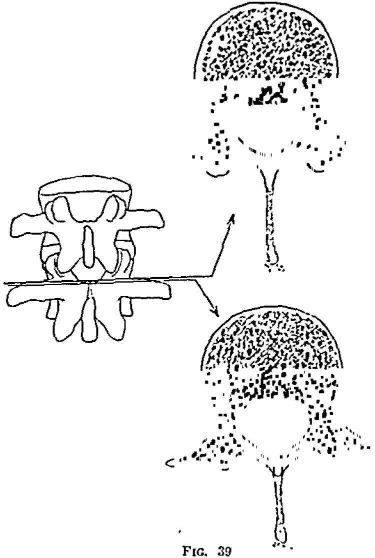

FIG. 39

Section through the uppermost part of the lamina of L.3.

Top.—The section here, in fact, passes through the lowermost part of the interlaminar foramen, and a gap in the bone filled by ligamentum flavum just allows access to the vertebral canal. The ligament is seen attached to the posterior surface of the lamina of the lower vertebra.

Bottom.—Immediately below the level of the interlaminar foramen. The approach to the vertebral canal is barred by the upper borders of the laminae.

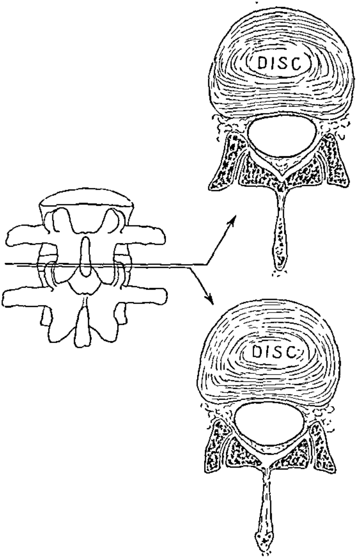

Fig. 38
Section through the disc between L.2, 3.

Top.—The approach to the vertebral canal is barred by the lower borders of the laminae of L.2. The ligamentum flavum is seen attached to the anterior surface of the lamina of the upper vertebra.

Bottom.—The section has passed through the apex of the interlaminar foramen

From the picture it will be realised that if, for one reason or another, it is intended to identify the extradural space, it is better for the needle to penetrate the ligamentum flavum as near the median plane as possible, where the space is deepest. If the needle is pushed through the ligament to one side of the median plane, it is very easy for it to go through the very narrow extradural space and dura with the same movement.

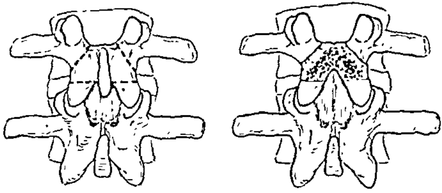

FIG. 41

The laminae have been cut into as indicated by the interrupted line and the spine has been removed. If the point of the needle is directed slightly cephalwards during lumbar puncture, it has a better chance of piercing the ligamentum flavum than if it is inserted at right angles to the skin.

FIG. 42

Almost the whole of the cerebellum has been removed and the pia-ependymal roof of the fourth ventricle is shown semi-diagrammatically. The fourth ventricle, the aqueduct of the midbrain and the third ventricle are enclosed by the interrupted line. The median aperture (foramen of Magendie) is shown and the two lateral openings (ff. Luschka) are indicated. Above the tentorium the cerebrum has been cut coronally and the optic tracts are seen lying on the sides of the midbrain. Below the tentorium the 5th, the 7th and 8th, the 9th, 10th and 11th, and the 12th nerves run across the cranial subarachnoid space to enter their foramina. Below the foramen magnum the cervical nerve roots are seen running across the spinal subarachnoid space to enter their corresponding intervertebral foramina.

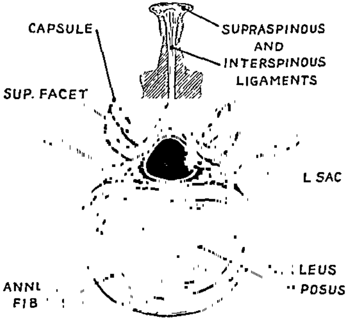

FIG. 40

An intervertebral disc on top of a lumbar vertebra has been cut through to show the annular fibrous outer cover surrounding the gelatinous nucleus pulposus.

The supraspinous and interspinous ligaments and the ligamenta flava are continuous. The ligamentum flavum is closely connected with the anterior aspect of the capsule surrounding the articular processes. It lies immediately posterior to the lumbar nerve roots (not shown) running from the dural sac across the extradural space to reach the intervertebral foramen. The facets of the superior articular processes of the lumbar vertebra are seen within their capsules. When the inferior articular processes of the upper vertebra are *in situ*, the breadth of the ligamentum flavum through which a lumbar puncture needle can be passed is much narrowed. The fat in the extradural space is most extensive posteriorly in the median plane, diminishing considerably on the two sides where ligamentum flavum and dura almost touch, and then increasing in volume laterally to become continuous with the fat in the intervertebral foramen.

The anterior part of the extradural space between the dura and the posterior aspects of the vertebral bodies and discs is very narrow but contains vessels and sometimes a thin strip of fat.

cortex from the cranial sensory nerves. Martin mentions the case of a woman subsequently found to have a small haemorrhage in the pons involving the medial and spinal fillets, the pathways by which sensory impulses are transmitted to the thalamus and cortex. When the haemorrhage was confined to one side she was anaesthetic on the opposite side of the body and drowsy. As the haemorrhage spread to involve both sides all afferent impulses to the cortex from below the level of the optic tracts were cut off. Sensory loss was now bilateral and the patient became extremely drowsy: if she closed her eyes she became unconscious, and could be roused only if they were forcibly opened.

When a person courts sleep, he does what he can to eliminate outside stimuli. A conscious patient is certainly in possession of some at least of his five senses. If a patient is deprived of all five senses can he remain conscious? The subject is one suitable for discussion by the philosopher, but the practical answer is probably contained in the observation that the higher a spinal anaesthetic spreads, the greater the tendency for the patient to become drowsy and lose consciousness in a way no more unpleasant than going to sleep. Tactile sensibility of the trunk is eliminated early, and if the spinal anaesthetic extends high enough to spread through the cranial subarachnoid space, taste, hearing, sight, and smell are also soon lost. Contact with the outside world is now lost and the patient becomes unconscious.

It is well known that in local and spinal analgesia, sensory nerve fibres are affected before motor. If the concentration of anaesthetic is low enough there can be sensory loss without motor paralysis. In really high spinal analgesia the skin over the neck (C.2, 3, 4) can be insensitive when the diaphragm, supplied by the motor roots of the phrenic (C.3, 4, 5), still functions. When the spinal analgesia is more extensive still, the patient loses consciousness. Even now diaphragmatic activity may be enough to sustain life. On the other hand respiration may cease and there is no means then of knowing whether the motor roots of the phrenic are affected, or whether some of the anaesthetic solution has entered the fourth ventricle and reached the respiratory centre located there. In either case the treatment is the same. Give artificial respiration, preferably with added oxygen, until the local anaesthetic is eliminated and normal respiration begins again. The dura-

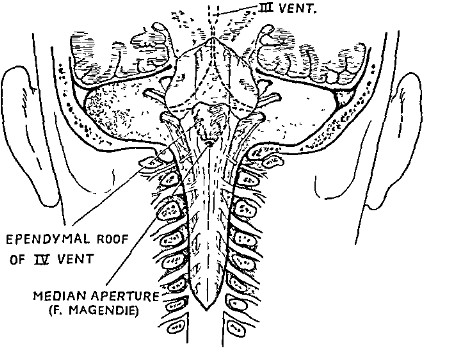

FIG. 42

This picture explains why a patient loses consciousness if the spinal anaesthetic solution spreads much higher than was intended.

It is commonly observed that if analgesia extends to the upper thoracic region the patient tends to become drowsy. Moreover, if now a general anaesthetic (*e.g.*, Pentothal) is superimposed only a very small amount is necessary to produce unconsciousness; and respiratory arrest follows the administration of doses which would not have this effect if the patient were not under a spinal anaesthetic.

Purdon Martin[1] has pointed out that consciousness is maintained by "an awareness of the body" and of the environment. Consciousness lapses in the absence of sensory impulses to the cortex. It is clear, and the writer can testify from personal experience, that the higher a spinal anaesthetic spreads the more the awareness of the body is diminished. The area from which the cortex receives *stimuli* is lessened. If the solution spreads to the foramen magnum, sensory stimuli from the body are eliminated and the patient remains awake by virtue of stimuli reaching the

part of the transverse colon. The sacral para-sympathetic or sacral outflow consists of fibres which leave the 2nd, 3rd and 4th sacral nerves to supply the splenic flexure, descending colon, and pelvic organs.

The abdominal wall is supplied by nerve fibres which enter and leave the cord between the 6th thoracic and 1st lumbar segments of the cord. It is seen therefore, that if a spinal anaesthetic reaches as high as T.5, the abdominal wall will be rendered insensitive and paralysed. Also the sympathetic nerve supply of the abdominal viscera will be interrupted, but the fibres of the vagi, because of their extra-thecal course remain unaffected.

When the abdomen is opened, the facts that the vagi contain sensory fibres and that they remain active, can be demonstrated by traction on the mesentery: nausea and a poorly localised but distressing abdominal discomfort result, the blood pressure falls and sweating of the head and neck is commonly observed. Provided the mesentery is not pulled on, an abdominal operation under reasonably high spinal analgesia can be carried out painlessly. In upper abdominal surgery a certain amount of traction appears to be almost inevitable, and in these cases the surgeon is well advised to infiltrate with local anaesthetic the vagus nerves on both the anterior and posterior surfaces of the cardiac end of the stomach to abolish the transmission of unpleasant stimuli via these fibres.

Motor paralysis of the splanchnic nerves is revealed by the contracted tape-like condition of the gut, and this effect is accentuated by the unopposed and unimpaired tonic action of the vagi on the muscle of the intestinal wall. This condition is the exact opposite of the contraction of the sphincters and the distension of the gut which frequently follows the operation of vagotomy in the treatment of gastric ulcer; for here the action of the splanchnic nerves on the gut is unopposed.

In high spinal analgesia the heart rate is affected. The rate at which the heart beats is an indication of the preponderance of the influence of the sympathetic or the para-sympathetic nervous system on that organ. The rate is increased by the action of the sympathetic cardiac accelerator fibres which leave the 2nd, 3rd and 4th thoracic segments, and the rate is decreased by stimulation of the vagus. If a spinal anaesthetic reaches as high as the upper thoracic nerve roots some of the sympathetic fibres to the heart

tion of the respiratory paralysis depends on the drug used: in the case of procaine the time is about an hour, and with Nupercaine or amethocaine the period may be up to two or even three hours. Provided the patient is kept well ventilated and well oxygenated during this time, he will be none the worse for the misadventure.

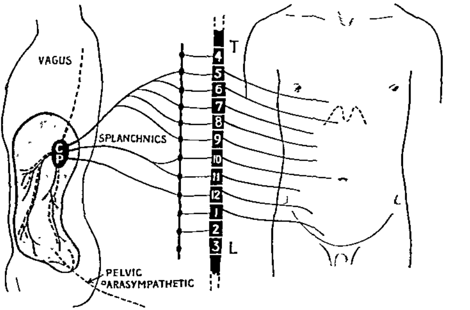

FIG. 43
(*After Lake.*[2])

FIG 43

The motor and sensory nerve supply of the abdominal viscera is derived from both sympathetic and para-sympathetic components of the autonomic nervous system. The sympathetic nerve fibres for these viscera leave the cord between the 5th thoracic and 1st lumbar segments, form the splanchnic nerves, and pass to the coeliac plexus whence they are distributed to the abdominal viscera. The visceral para-sympathetic nerves leave the central nervous system in two distinct parts. That section of the cranial para-sympathetic outflow which supplies the viscera consists of fibres in the vagi nerves which run their course outside the vertebral canal to enter the abdomen, innervate the stomach, and communicate freely with the coeliac plexus through which they are distributed to the rest of the alimentary canal up to the distal

part of the transverse colon. The sacral para-sympathetic or sacral outflow consists of fibres which leave the 2nd, 3rd and 4th sacral nerves to supply the splenic flexure, descending colon, and pelvic organs.

The abdominal wall is supplied by nerve fibres which enter and leave the cord between the 6th thoracic and 1st lumbar segments of the cord. It is seen therefore, that if a spinal anaesthetic reaches as high as T.5, the abdominal wall will be rendered insensitive and paralysed. Also the sympathetic nerve supply of the abdominal viscera will be interrupted, but the fibres of the vagi, because of their extra-thecal course remain unaffected.

When the abdomen is opened, the facts that the vagi contain sensory fibres and that they remain active, can be demonstrated by traction on the mesentery: nausea and a poorly localised but distressing abdominal discomfort result, the blood pressure falls and sweating of the head and neck is commonly observed. Provided the mesentery is not pulled on, an abdominal operation under reasonably high spinal analgesia can be carried out painlessly. In upper abdominal surgery a certain amount of traction appears to be almost inevitable, and in these cases the surgeon is well advised to infiltrate with local anaesthetic the vagus nerves on both the anterior and posterior surfaces of the cardiac end of the stomach to abolish the transmission of unpleasant stimuli via these fibres.

Motor paralysis of the splanchnic nerves is revealed by the contracted tape-like condition of the gut, and this effect is accentuated by the unopposed and unimpaired tonic action of the vagi on the muscle of the intestinal wall. This condition is the exact opposite of the contraction of the sphincters and the distension of the gut which frequently follows the operation of vagotomy in the treatment of gastric ulcer; for here the action of the splanchnic nerves on the gut is unopposed.

In high spinal analgesia the heart rate is affected. The rate at which the heart beats is an indication of the preponderance of the influence of the sympathetic or the para-sympathetic nervous system on that organ. The rate is increased by the action of the sympathetic cardiac accelerator fibres which leave the 2nd, 3rd and 4th thoracic segments, and the rate is decreased by stimulation of the vagus. If a spinal anaesthetic reaches as high as the upper thoracic nerve roots some of the sympathetic fibres to the heart

are put out of action. The action of the vagus now predominates and the heart rate slows, commonly to 45-60 per minute. The opposite of the bradycardia occasioned by a high spinal anaesthetic is seen when for one reason or another (*e.g.*, preparatory to a laryngeal or a thoracic operation) the vagi are paralysed by injecting them with procaine at their exits from the jugular foramina. Their braking influence on the heart rate is temporarily removed, and as the sympathetic accelerator fibres are unopposed the pulse rate leaps up by 50 per cent. or more of its normal rate.

Figure 43 can be used too to emphasise the point that both the good and the bad effects of spinal analgesia depend not on the mass of local anaesthetic drug injected, but on the height within the dura which the drug reaches. Let us assume that Nupercaine solution is injected and reaches the 6th thoracic segment of the spinal cord. *All the desirable results of this—the freedom from pain* below this level, the relaxation, and the lack of response to surgical stimuli are due to the fact that the drug has reached just this level. Similarly any ill effects—for example, low blood pressure and impaired respiratory exchange due to paralysis of intercostal muscles —are attributable to the same cause. The good and the bad effects depend not in the least on whether the patient is given 10 or 15 mg. of Nupercaine; they depend on the level within the dural canal reached by the drug. If in each case the drug reaches the same cord level the results are indistinguishable. Let me put it in another way. Lake (p. 120) sees merit in his technique because analgesia for abdominal surgery is obtained with 8 or 9 cc. of dilute Nupercaine solution, whereas another method, perhaps less disturbing to the patient, needs 15 cc. The economy of 6 or 7 cc. of 1/1,500 Nupercaine solution (equivalent to only 4 mg. of Nupercaine!) is quite pointless since, if the operation were to be carried out under nerve block or local infiltration analgesia, the anaesthetist would have no qualms about injecting 150 cc. or even more of the same solution.

The point can be illustrated further by a story. The feature generally deplored in high spinal analgesia is the fall in blood pressure due to involvement of the fibres of the sympathetic nerves as they leave the cord. I remember being present during a cholecystectomy by Kirschner His technique of spinal anaesthesia was followed, in which a small amount of Nupercaine is injected high

in the vertebral canal—between the 11th and 12th thoracic vertebrae. Soon skin analgesia was demonstrated to the 5th thoracic segment. During the course of the operation the abdominal relaxation was excellent, the fall in blood pressure obvious, and the general condition rather poor. The only point to which the surgeon drew attention, and that with some pride, was quite irrelevant to the patient's general condition. This particular spinal anaesthetic technique often spares the cauda equina and the surgeon encouraged the man to demonstrate that he could still move his legs, though weakly. Ability to move his legs is indeed a desirable attribute of a man on the football field or dance floor, but it is no criterion of his well-being when playing the role of patient on the operating table. It is better for the patient if attention is focussed less on some unimportant detail and more on essentials such as giving him additional oxygen to compensate for his impaired respiratory efficiency (see p. 131).

FIG. 44

Lumbar vertebrae 1, 2, 3. The last thoracic and first two lumbar nerves on the left side are seen leaving the intervertebral foramina surrounded by fat, which is continuous with the fat in the extradural space.

FIG. 45

The pedicles have been sawn through, and the vertebral arches of L.1 and 2 have been removed, showing the contents of the vertebral canal.

FIG. 46

The fat and vessels of the extradural space have been cleared leaving the main structures in the vertebral canal, the cord and membranes running vertically, and the spinal nerve roots in their dural sheaths running almost horizontally, to reach their intervertebral foramina.

FIG. 47

The cord and membranes have been removed to show the posterior longitudinal ligament forming the continuous anterior boundary of the vertebral canal.

Fig. 44

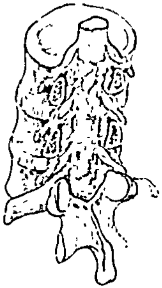

Fig. 45

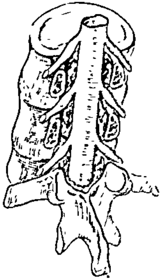

Fig. 46

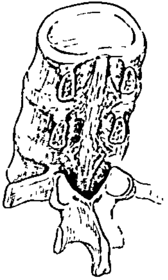

Fig. 47

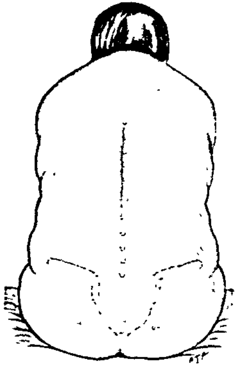

FIG. 48

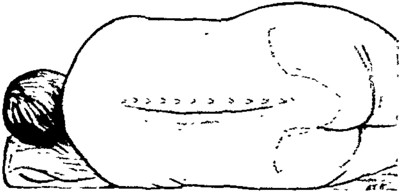

FIG. 49

The skin over the midline of the back is commonly connected by fibrous strands with the supra-spinous ligament, a local condensation of the lumbar aponeurosis. When a fat patient is sitting, the resultant furrow between the layers of fat over the lumbar muscles is central (Fig. 48). If she lies down on one side the furrow may remain almost in the midline; but usually it sags considerably below the line joining the spinous processes (Fig. 49). The spines are not readily palpable, but the anaesthetist must not be tempted to be guided by sight when deciding where to insert his needle: for if he accepts the furrow as a landmark he will start frequently well lateral to where he imagines himself to be. He should dig his fingers deeply into the back to find the midline. Individual spinous processes will not be recognised, but the general direction taken by them will.

With the really fat patient the difficulties of lumbar puncture may be increased for two reasons. The first is the uncertainty in defining the outline of any one spinous process from which the course of the needle is set; and the second is that the depth at which the cerebro-spinal fluid will be encountered cannot be predicted accurately. It is in these cases, where the course of the needle may have to be changed once or twice before success is achieved, that the anaesthetist is advised to avail himself of a director (p. 97), and to keep to the midline throughout.

The distance the needle must be inserted before the extradural space is reached is remarkably constant in the average individual, but it is much more difficult to estimate in the fat subject. Gutierrez[3] in a personal series of 3,200 cases, found the distance varied from 1 to 5 inches, but in 80 per cent. of this large series the range narrowed down to $1\frac{1}{2}$ - 2 inches. The increased depth in fat people is due primarily to the fat in the subcutaneous tissue, but depends also on the angulation of the needle. If the needle happens to go in almost at right angles (Fig. 50A), the depth will be much less than if it has to be angulated steeply (B_1) to avoid the lamina.

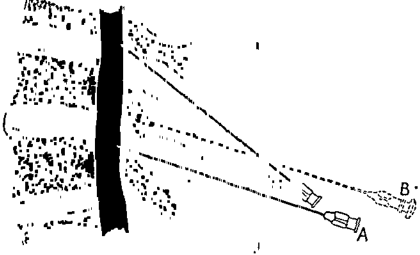

FIG. 50

The posterior surface of the lamina of a lumbar vertebra slopes downwards and backwards. The upper border lies at the same depth as the ligamentum flavum which is attached to it; the lower border is considerably more superficial. In patients of average build the distance from the skin to ligamentum flavum varies little from 1½ inches. If, therefore, the needle, slightly out of the median plane, encounters bone at a shallow depth, it is the lower border of the lamina on which it impinges; if the obstruction is deep it is the upper border. This information is of great help when deciding what alteration should be made in the angle at which the needle is re-inserted.

FIG. 51

Although the distribution of the intercostal nerves overlaps slightly, the skin over the abdominal wall and the lower part of the thorax is generally regarded as being innervated in serial bands from the corresponding segments of the cord. The skin over the lowest part of the abdominal wall is supplied by L.1. If the anaesthetic spreads to the 10th thoracic nerve roots analgesia of the skin extends up to the umbilicus The 6th intercostal nerve supplies the skin at the level of the xiphisternum.

When a spinal anaesthetic is given for an upper abdominal operation, it can be predicted with considerable assurance that analgesia of the parietes will reach, and stop at, the nipple line. If

a heavy solution is injected the reason can be found in figures 88 and 105. But even if a totally different technique is followed, skin analgesia is practically sure to *stop at the same landmark*. The explanation lies in the fact that the skin over the upper part of the thorax has a double innervation: it is supplied not only by the corresponding intercostal nerves but by the descending branches *of the cervical plexus which join the 3rd and 4th cervical segments*

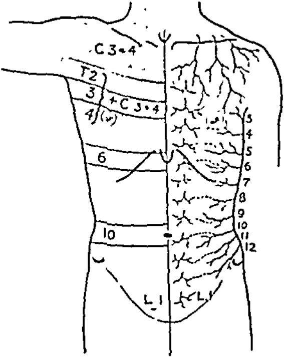

FIG. 51

of the cord. Even if the spinal anaesthetic solution were to spread as high as C.5—high enough to anaesthetise the skin of the upper extremities—the skin over the thorax above the nipple line, and over the shoulders, would still be sensitive.

Following the successful treatment of megacolon with spinal analgesia, attempts have been made to treat achalasia of the oesophagus by paralysing temporarily the sympathetic nerve supply to that organ. Sympathetic fibres come off as high as the 1st thoracic segment of the cord: if, therefore, the spinal anaesthetic

solution is made to reach as high as this, paralysis of sympathetic fibres to the oesophagus is assured. Two problems arise: how can one be satisfied that the level aimed at has been reached, and what technique should be used? Horner's syndrome of paralysis of the upper sympathetic fibres cannot be appreciated when it is a consequence of high spinal analgesia, since the effect is bilateral: it is the contrast between the eyes resulting from unilateral paralysis which makes the condition obvious. Loss of sensation of the skin is no accurate guide as to how high sympathetic or motor paralysis extends. If, however, the interosseus muscles (innervation C.8, T.1) *of the hand are paralysed—a condition revealed by the patient* being unable to grip firmly a piece of paper between outstretched fingers—it is reasonably certain that the uppermost sympathetic fibres, which accompany the motor fibres in the anterior roots of the 1st pair of thoracic nerves, will also be involved.

The first time I was presented with this problem I administered 300 mg. of procaine crystals with barbotage: analgesia of the skin extended up to the nipple line, but the interosseus muscles were not paralysed. After fifteen minutes I repeated the lumbar puncture and gave a further 100 mg. procaine with barbotage, without causing a change in the patient's condition. After a further fifteen minutes the procedure was again repeated without any change. It has long been suspected and recently recognised[1] that absorption into the capillaries of the spinal cord, of substances injected by lumbar puncture, takes place rapidly. Possibly 100 mg. of procaine could be injected into the lumbar subarachnoid space every fifteen *minutes almost indefinitely, without causing paralysis of any of* the motor fibres of the brachial plexus. After the third injection, by which time a total of 500 mg. of procaine had been given, the attempt was abandoned until the next day. Then the object was successfully accomplished by giving 400 mg. in one dose with barbotage. In an average fit man this procedure results in temporary paralysis, or marked weakness, of the muscles of the arms at a time when respiration remains just adequate.

The methods by which a local anaesthetic drug, injected into the lumbar subarachnoid space, is distributed to the nerve roots on which it is desired to act are discussed elsewhere (p. 102). If barbotage is employed the intensity of the analgesic action and the extent of the spread depend on a combination of the mass of drug and the

vigour of the barbotage. If only a small amount of local anaesthetic is administered no amount of barbotage will cause widespread paralysis. On the other hand, a gross over-dose will not cause a wide distribution in the absence of barbotage. I know of three consecutive cases in which the surgeon inadvertently administered 1 gram (!) of procaine crystals instead of the intended 200 mg. The injections were made with the patient in the lateral position, and barbotage was not employed. At the time of operation nothing untoward was noticed, and the error was discovered only on the next day when the patients remarked on extensive areas of analgesia and incomplete recovery of muscular power, a state of affairs which did not clear up completely until a few days afterwards. If prolonged barbotage had been employed in any of these cases it is certain that the gross over-dose would have caused respiratory arrest.

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CHAPTER V

Sterilisation

WITH the methods of sterilisation formerly in vogue, it is surprising that the sequelae to spinal analgesia were not both more serious and more common than they appear to have been. As late as 1929, we find Gwathmey[1] advocating that stock cocaine crystals should be "sterilised" by adding ether and stirring until the latter evaporates; boiled or filtered water is then added to make a 2 per cent. solution. This procedure was originally recommended by Bainbridge,[2] who although observing that "this simple way of sterilising may be open to bacteriological objections," added reassuringly "practical experiments, as far as I know, have proven it to be satisfactory." Choyce's *Surgery*[3] quotes Jonnesco as saying that it is unnecessary to sterilise the stovaine used for spinal analgesia—"the strychnine [added to his special solution] being sufficiently antiseptic to obviate any dangers of sepsis." In 1909, in an article on spinal analgesia,[4] we read the dangerous statement, often since repeated, that local anaesthetics are self sterilising: "the necessary quantity of stovaine, tropacocaine or novocaine is introduced into a sterilised glass tube . . . but the substances need not be sterilised since they are themselves antiseptic and some of their properties would be destroyed by heat."

Meningeal infection is a grave complication of spinal analgesia, and responsibility for it must be accepted by the anaesthetist if it occurs, as being due either to personal failure in carrying out a satisfactory aseptic technique, or to condoning faulty preparation of needles, syringes, etc. Many different ways of ensuring asepsis have been described. The optimum technique would reduce to a minimum loopholes for the introduction of noxious agents into the theca, and yet at the same time be simple enough to be understood by those playing their part in carrying it out, and straightforward enough not to invite slipshod performance. As in many other branches of medicine, there must be a compromise between what is ideal and what is practicable.

If sepsis could be eliminated, one of the great hazards of spinal analgesia would disappear, and sepsis can be eliminated by the

exercise of a reasonable amount of care, commonsense, and discipline. Obvious potential sources of infection are the patient's skin, the operator, and the syringes, needles and drugs: and the problem can conveniently be considered under these three headings. The means of avoiding infection described here, have given satisfactory results in a teaching hospital for over fifteen years.

The Patient's Skin

The skin is prepared immediately before lumbar puncture. The patient is placed in position and the back widely cleared of clothes, towels and bandages. A solution of 2 per cent. iodine in 70 per

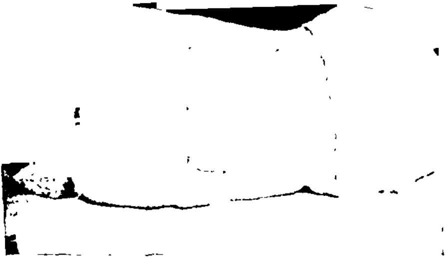

FIG. 52
The outline of iodine clearly defines the sterilised area. The level of the crest of the ilium is painted also. A line dropped from this passes between the spinous processes of the 3rd and 4th lumbar vertebrae, or through the 4th process.

cent. alcohol is applied by a sterile wool swab first to the site of puncture, and then over an area extending for about six inches on either side of the lumbar and lower thoracic spines. The intended point of entry of the needle is localised by touch, after which the prepared area is repainted and the fingers should not subsequently come into contact with the skin near the point of entry.

The alcoholic solution of iodine rapidly disinfects the skin.[5] It has the added advantage that the colour clearly defines the area

prepared, so that an onlooker or the anaesthetist may notice if the hands of the latter should stray outside it. A sterile towel is placed between the underside of the patient and the table, but any attempt at draping the lumbar area is deliberately avoided, since an unclipped towel might move and the unsterile undersurface spread contamination to the prepared area.

Obvious infection of the skin of the back contra-indicates lumbar puncture. Difficulty sometimes arises in deciding whether to give a spinal anaesthetic to a patient who already has a colostomy or a cystostomy, or is otherwise incontinent. On general principles a spinal anaesthetic should be avoided here, but on many occasions I have disregarded this counsel of perfection when I felt that the increased risk of sepsis was outweighed by the improved operating conditions offered by spinal analgesia for that particular case. No harm has resulted, probably because of meticulous care in preparing the site of puncture.

The Operator

Nose and mouth are covered with a mask. Ideally the hands should be prepared and gloved as for a surgical operation, and maintained sterile; but the application of gloves solely as a ritual, with little consideration as to whether they subsequently become contaminated or not, is much to be condemned. I have often given a spinal anaesthetic without using gloves. In these circumstances, the hands are cleansed by vigorous scrubbing with soap and water for five to seven minutes,[6] rinsing under running water, and drying carefully on a sterile towel. Strict attention is paid to what is virtually a "no-touch" technique. Care is taken to keep the fingers well away from the nozzle of the syringe, and fingering the openings at either end of the needle is avoided by using a needle with light metal flanges[7] as illustrated on page 84. On the rare occasions when the shaft of a long needle has to be steadied during insertion, it is held in a sterile swab.

Syringes, Needles and Drugs

From experience as an onlooker at various hospitals, even those in which admirable facilities for sterilising exist, I have formed the opinion that asepsis in spinal analgesia is most likely to break down through faulty sterilisation of apparatus and drugs. Here

are some examples of risks to which the patient is quite needlessly exposed:—

1. Syringes and needles are "sterilised" by methods not above suspicion, *e.g.*, by immersion in spirit.

2. Syringes and needles are rinsed out with so-labelled "sterile distilled water" from a flask which has already been opened for some time, or the rinsing water is poured from a flask, the outlet of which quite obviously cannot be sterile.

3. An intradermal wheal is made with local anaesthetic drawn from a rubber-stoppered stock bottle, after which the spinal needle is passed through this now possibly infected area.

4. An assistant is asked to open, with a non-sterile file, an ampoule of the local anaesthetic to be injected intrathecally; and it is taken for granted that the solution remains uncontaminated by filings or small fragments of glass.

None of the above risks is justified, for it is an easy matter to sterilise every instrument and drug used in giving a spinal anaesthetic.

I cannot too strongly recommend the procedure to be described, both as a guarantee of sterility and as a convenience to the anaesthetist. The following items are fitted into a home-made strip of linen or lint threaded with tape so that each item is held separately:—

2 lumbar puncture needles and stilettes.
1×20 cc. all glass syringe.
1×5 cc. all glass syringe.
1×2 cc. all glass syringe.
[illegible]
[illegible]
[illegible]
1 file.
1 swab holder.
3 or 4 swabs.
1 hypodermic needle.
1 stouter needle of wider bore.

The pack is rolled, placed in a small metal drum 7 inches high $\times 4$ inches diameter, with a lid fitted with a sliding port at either end. The drum with both end ports open, is placed in an autoclave and sterilised by steam at a gauge pressure of 20 lbs. per sq. inch

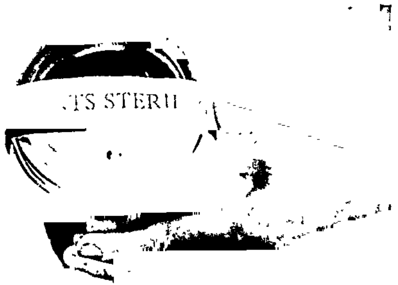

FIG. 53
The small metal drum containing everything necessary for lumbar puncture and spinal analgesia has been autoclaved.

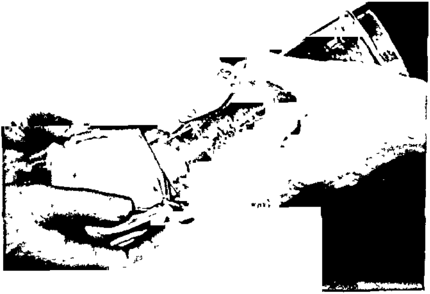

FIG 54
The lid is taken off and the rolled contents are tipped into the anaesthetist's gloved hands.

for thirty minutes. At this total pressure of just over 2 atmospheres, the temperature of saturated steam is 126°C.

The syringes should be all glass, since many of the glass-metal type will not withstand autoclaving: either the glass cracks because of the unequal expansion of glass and metal, or the cement binding the two softens.

When the drum has been autoclaved, both ports are closed and labelled *sterilised* in such a way that the label is broken if a port is inadvertently opened, or if one of the ends of the drum is removed. The prepared drum can be kept for weeks, and can be transported with ease.

FIG. 55
The bundle is placed on a sterile towel, and unrolled.

When the contents are to be used, an assistant takes one of the ends off the drum, thus breaking the label. The drum is now tilted so that the rolled contents slide out into the anaesthetist's prepared hands. The roll is untied, placed on a sterile towel, opened out, and everything is ready. The chance of infection from the opening of ampoules does not now exist, and if an intradermal wheal is to be made, local anaesthetic solution is taken from one of the spare ampoules originally intended for spinal analgesia.

Exceptional circumstances may justify the acceptance of less absolute methods of sterilising instruments. The single-handed medical officer of a ship may consider an operation less hazardous under spinal analgesia given by himself, with a syringe prepared by boiling, than under general anaesthesia given by a lay anaesthetist.

All non-sporing and many sporing organisms are killed by boiling for five minutes.[7] If sterilisation by boiling is to be adopted, syringes and needles should first be washed until perfectly clean, as organisms in pus or inspissated mucus have greatly increased resistance to boiling. The instruments are placed in a pan of warm water, brought to the boil and left for five to ten minutes. The pan, still containing sufficient water to cover the instruments, is then removed from the source of heat, protected by a sterile towel, and allowed to cool.

The instruments should be boiled as near the time of operation as is practicable; and they should not be removed from the water until they are to be used for lumbar puncture. The fault to be found with boiling as a means of sterilisation is not so much the inadequacy of boiling as the ease with which contamination tends to be introduced afterwards, *e.g.*, from cooling by addition of "sterile" water, or storing in "sterile" water, or handling. Attention is drawn particularly to the warning on page 133 of the danger of storing spinal anaesthetic solutions in spirit or other antiseptics.

Should it be desired to rinse the syringes before using, this can be done with the spinal anaesthetic solution itself, or with distilled water from ampoules such as those supplied with Pentothal.

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CHAPTER VI

Technique of Lumbar Puncture

IN any manoeuvre in which direction is important, the eye should be on the same planes, vertical and horizontal, as the tools being used. During lumbar puncture, therefore, the eye should be behind the hub of the needle looking along the line of the shaft (Fig. 56).

FIG. 56

The anaesthetist should sit down to his job. This serves the treble purpose of making him comfortable, steadying his movements and bringing his eye much more nearly to the horizontal plane of the field of operation. Some find lumbar puncture easier with the patient sitting up, and the logical explanation is that in this position, the site of puncture is higher off the table, and more nearly on a level with the anaesthetist's eye, which is therefore better placed for accurate corrections to be made to the direction of the needle.

The needle aims at penetrating the ligamentum flavum, for once this is done, lumbar puncture is virtually over. Whether the patient is lying down or sitting up is immaterial. What *is* important is that the lumbar vertebrae should be flexed on each other as far as

FIG. 57
What not to do.

possible; for in flexion the inferior articular processes of the upper vertebra ride up on the superior articular processes of the lower, the ligamenta flava are stretched and the interlaminar spaces are increased (Fig. 63B). In other words, flexion of the lumbar vertebrae increases the size of the target at which the needle aims.

Flexion of the thighs on the spine does not necessarily cause flexion of the lumbar vertebrae. It is not sufficient to tell the patient when sitting to "bend well forwards," or when lying down, to "draw your knees up to your chin." A better position results from instructions such as "try to arch your back like a cat," "try to roll your head into your lap," or, with a finger-tip on the lumbar area, "I want you to push out this part of your back." If the trolley or bed sags, the raised edge makes it difficult to carry out lumbar puncture with the patient lying down, he should therefore sit up

so that the needle can be introduced in the proper plane. If the trolley is flat and firm, the patient can lie down. The assistant should concentrate on flexing the lumbar vertebrae. If the patient is sitting, the thighs are already flexed, so that all that is necessary is to flex the neck well towards the lap. When the patient is lying down, flexion of the lumbar vertebrae is encouraged by an assistant

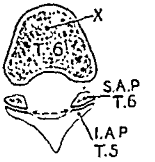

FIG. 58

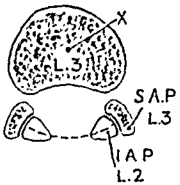

FIG. 59

FIG. 58—The disposition of the facets on the articular processes of a thoracic vertebra allow rotation of one vertebra on another. If X is the centre of rotation the circumference of a circle lies in the same plane as the articular surfaces of the processes.

FIG. 59—In the lumbar region, however, the circumference of a circle drawn from X passes at right angles to the plane between the facets on the articular processes of two vertebrae: rotation cannot take place. (*After Frazer.*[1])

firmly flexing the neck, and raising the knees to meet the down-coming head. During this manoeuvre there is a tendency for the assistant's mouth, nose and hair to project immediately over the area to be kept sterile (Fig. 57); this is obviously undesirable, so that the puncture is not commenced till the assistant's head is well out of harm's way (Fig. 56). It is desirable, but not essential, that the patient's shoulders should be kept level with each other; a certain amount of rotation of the thoracic vertebrae does not matter, since the disposition of the articular facets on the processes of the *lumbar* vertebrae prevents rotation taking place there (Fig. 59).

An appropriate site for lumbar puncture is easy to estimate, for a line joining the highest points of the two iliac crests passes just above the 4th lumbar spine. The precise level is a matter of indifference provided it is below L.2. The distances between the

The needle aims at penetrating the ligamentum flavum, for once this is done, lumbar puncture is virtually over. Whether the patient is lying down or sitting up is immaterial. What *is* important is that the lumbar vertebrae should be flexed on each other as far as

FIG. 57
What not to do.

possible; for in flexion the inferior articular processes of the upper vertebra ride up on the superior articular processes of the lower, the ligamenta flava are stretched and the interlaminar spaces are increased (Fig. 63B). In other words, flexion of the lumbar vertebrae increases the size of the target at which the needle aims.

Flexion of the thighs on the spine does not necessarily cause flexion of the lumbar vertebrae. It is not sufficient to tell the patient when sitting to "bend well forwards," or when lying down, to "draw your knees up to your chin." A better position results from instructions such as "try to arch your back like a cat," "try to roll your head into your lap," or, with a finger-tip on the lumbar area, "I want you to push out this part of your back." If the trolley or bed sags, the raised edge makes it difficult to carry out lumbar puncture with the patient lying down; he should therefore sit up

so that the needle can be introduced in the proper plane. If the trolley is flat and firm, the patient can lie down. The assistant should concentrate on flexing the lumbar vertebrae. If the patient is sitting, the thighs are already flexed, so that all that is necessary is to flex the neck well towards the lap. When the patient is lying down, flexion of the lumbar vertebrae is encouraged by an assistant

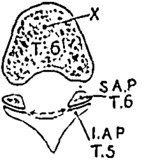

FIG. 58

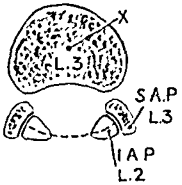

FIG. 59

FIG. 58—The disposition of the facets on the articular processes of a thoracic vertebra allow rotation of one vertebra on another. If X is the centre of rotation the circumference of a circle lies in the same plane as the articular surfaces of the processes.

FIG. 59—In the lumbar region, however, the circumference of a circle drawn from X passes at right angles to the plane between the facets on the articular processes of two vertebrae: rotation cannot take place. (*After Frazer.*)

firmly flexing the neck, and raising the knees to meet the down-coming head. During this manoeuvre there is a tendency for the assistant's mouth, nose and hair to project immediately over the area to be kept sterile (Fig. 57); this is obviously undesirable, so that the puncture is not commenced till the assistant's head is well out of harm's way (Fig. 56). It is desirable, but not essential, that the patient's shoulders should be kept level with each other; a certain amount of rotation of the thoracic vertebrae does not matter, since the disposition of the articular facets on the processes of the *lumbar* vertebrae prevents rotation taking place there (Fig. 59).

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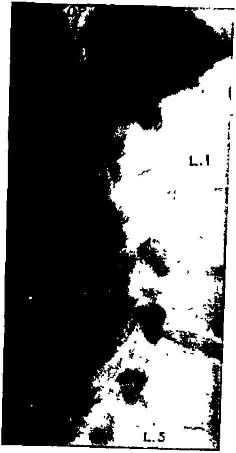

FIG 60A

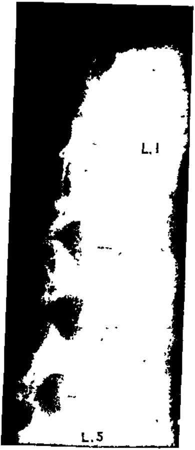

FIG. 61A

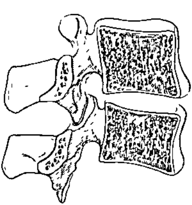

FIG. 60B
EXTENSION

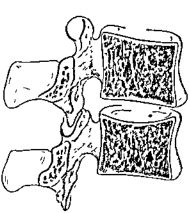

FIG 61B
FLEXION

FIG. 62A

FIG. 63A

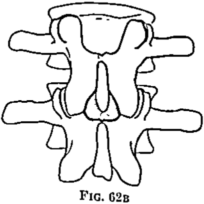

FIG. 62B
EXTENSION

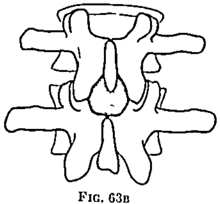

FIG. 63B
FLEXION

lumbar spines may vary and the anaesthetist is well advised to choose the space where the gap is widest. The optimum point to make the skin puncture is easy to determine in the average patient in whom the spines are easily palpated, but an element of luck and guesswork enters into the calculation when the patient is obese enough for the landmarks to be obscured with a thick roll of fat. The identification of individual spinous processes in the elderly may be difficult, too, even though the patient is quite thin, as his supraspinous ligament is usually of bony firmness to the touch. Here the lumbar vertebrae are often practically fixed in a slightly extended position; the spinous processes are close together and the exploring fingers feel a uniform hard ridge in which it is difficult to locate an interspinous interval with confidence.

By the time an interspinous space is identified and selected the anaesthetist will probably already have made up his mind whether to make a median puncture through the supraspinous ligament, or one immediately lateral to it. On the whole I favour the lateral approach, since the ligament can be very tough to pierce, and it can quite easily bend or deflect the course of a fine spinal needle. An intradermal wheal is raised with the smallest needle available at the level of the upper border of the lower spine and just lateral to the supraspinous ligament (Fig. 68). Now the small hypodermic needle is changed for a more robust one, and the tissues leading to the interlaminar space are generously infiltrated with two or three cc. of local anaesthetic solution.

The anaesthetist now has a second minor decision to make—whether to use a lumbar puncture needle only, or to use a needle director as well (p. 97). In the first case the needle with its stilette in place is inserted through the skin wheal and directed slightly upwards to miss the lamina of the lower vertebra, and slightly medially to compensate for the lateral start. The object is to encounter the ligamentum flavum in the centre of the interlaminar space. The needle passes through the skin, superficial fascia, a varying thickness of fat, lumbar aponeurosis into the lumbar muscles. In a thin patient these structures may not be identified separately by the needle, but in a robust subject the tough lumbar aponeurosis can generally be detected, and in an obese patient, too, the gradually advancing needle senses the difference in resistance

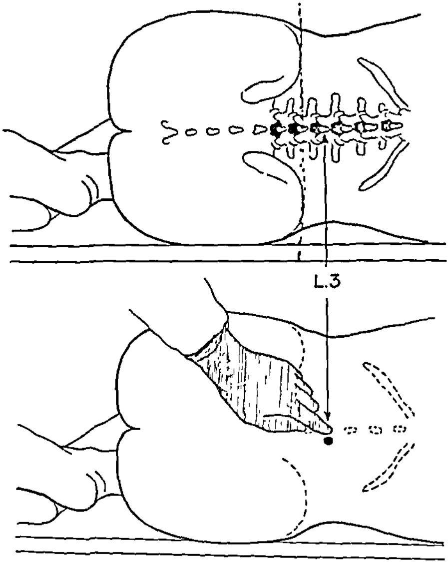

Fig. 64
Compare with Fig. 68.

Fig. 65

The 12th thoracic and the five lumbar spinous processes are indicated. It was Tuffier who first advised that lumbar puncture should be carried out at the level of a line joining the iliac crests; and for a time this was known as Tuffier's line

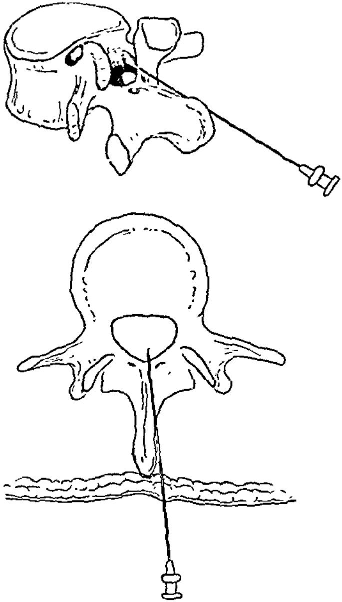

Fig. 66

The point of the needle is directed slightly upwards to steer clear of the upper margin of the lamina below, and slightly medially to compensate for its lateral start.

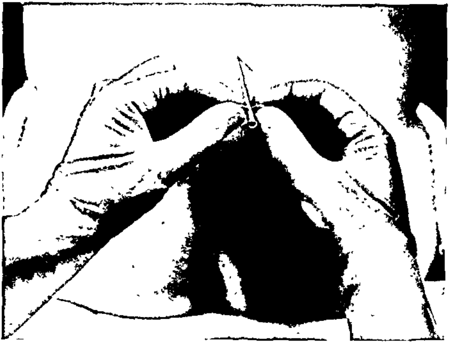

FIG. 67
Compare with Fig. 66.

FIG. 68
A wide space between two lumbar spines is chosen, in this case L.2-3. The left index finger palpates the spine of L.3 and a hypodermic wheal of local anaesthetic is raised immediately lateral to its upper border.
Compare with Fig. 64

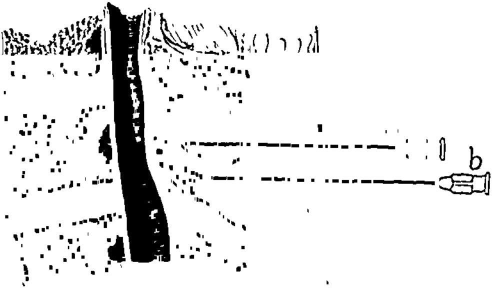

FIG. 69
The posterior surface of the lamina of a lumbar vertebra slopes downwards and backwards. If therefore the needle, slightly out of the median plane, encounters bone at a shallow depth, it is the lower border of the lamina on which it impinges; if the obstruction is deep, it is the upper border.

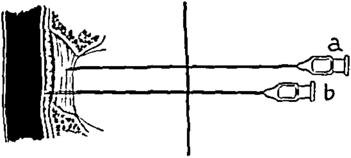

FIG. 70
The ligamentum flavum can often be recognised as the needle enters it (*a*), and in a powerful subject a second alteration in resistance may be detected as the needle passes through the distal side (*b*) to enter the extradural space.

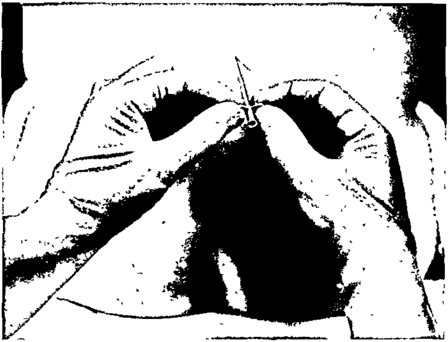

FIG. 67
Compare with Fig 66.

FIG. 68

L.2-3
wheal
border,

strongly developed. Once the ligamentum flavum is penetrated lumbar puncture is as good as done. The needle now lies within the vertebral canal and if pushed a little deeper almost inevitably pierces the dura. It is true that a needle somewhat ill directed may go through the ligamentum flavum and on its onward course fail to pierce the dura but touch it like a tangent to a circle. In these circumstances the point of the advancing needle may strike the

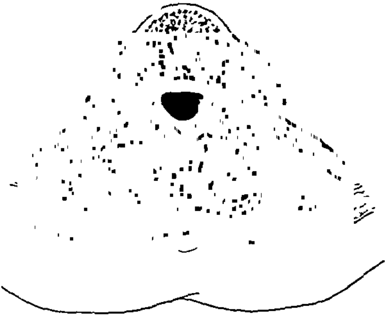

FIG. 72

nerve for that segment in the extradural space (Fig. 73) causing pain in the appropriate distribution. The side on which the pain is felt gives the clue to which side the needle has erred; and the necessary alteration in direction can generally be confirmed by looking along the line of the shaft. During an attempt at lumbar puncture, a shooting pain in the thigh unaccompanied by an issue of cerebro-spinal fluid shows that the point of the needle has passed through the ligamentum flavum and that either it is in the position just discussed, or else, though highly unlikely, that it has penetrated the dura and struck one of the constituent nerve roots of the cauda equina, but on account of blockage of the needle cerebro-spinal fluid does not flow through it.

The distance between the skin and the ligamentum flavum is determined partly by muscular development, but principally by

between the fatty and fibrous tissue. The anaesthetist at this stage should have a mental picture of the underlying structures, so that in the event of bone being encountered the needle can be slightly withdrawn and appropriate correction made in its direction. This

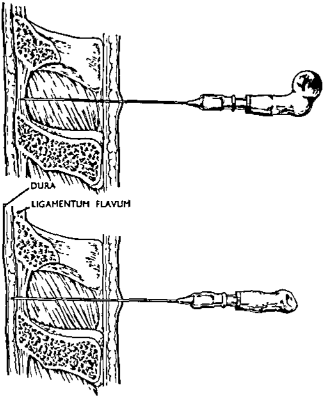

FIG. 71

It is an interesting practice to identify the extradural space as the needle passes through it during lumbar puncture One way of doing this is illustrated above. The small balloon inflated with air collapses immediately the needle passes through the ligamentum flavum into the extradural space, where the pressure is sub-atmospheric.

is a convenient time to take out the stilette. The chances of the point of the needle now becoming blocked with tissue are very small, and if by any chance the dura is penetrated unexpectedly, a flow of cerebro-spinal fluid through the free needle will reveal the situation. The resistance of the ligamentum flavum can generally be appreciated, particularly in the robust male in whom it is

In powerful men in whom the elastic ligament may be one-third of an inch thick, the needle can be felt to enter the ligament and after being pushed forwards some distance a second alteration in resistance is noted. This latter may give the impression that the

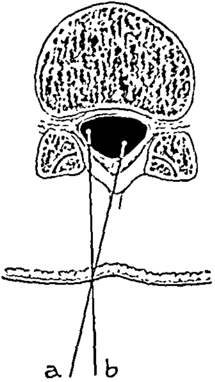

FIG. 71

dura has been pierced whereas it is caused by the point of the needle passing through the further side of the ligament into the extradural space (Fig. 70). When it occurs, this double resistance coupled with the absence of an issue of cerebro-spinal fluid locates the point with considerable certainty in the extradural space; if now the needle is pushed on further, the resistance of the dura will be noted and when this is pierced cerebro-spinal fluid will issue. If the needle is felt to enter the ligamentum flavum and immediately beyond is held up by bone, it shows that the point must

the amount of fat in the subcutaneous tissue (Fig. 50). After a little experience the depth at which the extradural space will be encountered in any particular case can generally be estimated with considerable accuracy. In a straightforward lumbar puncture the ligamentum flavum and the dura can usually be identified separately by the resistances they offer to the needle; this is made possible by

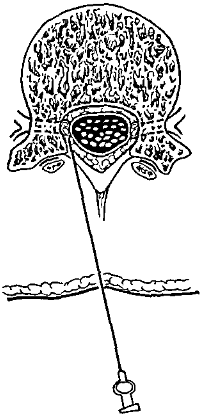

FIG. 73

the intervening layer of extradural fat which may be as deep as *one-third of an inch in the median plane.* But this is not always the case. Occasionally—particularly where the needle pierces the ligamentum flavum to one side of the median plane—resistance is felt only at one point, since the ligament and the dura are in actual contact in this situation (Fig. 74B).

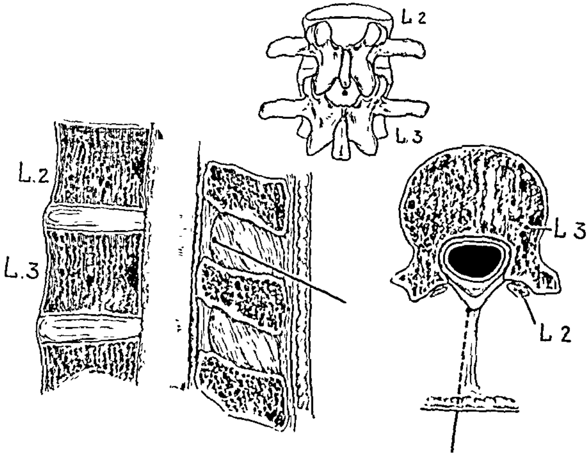

Fig. 76

Correct angulation of needle for lumbar puncture in an average subject.

The skin is punctured immediately to one side of the supraspinous ligament — in this case, the left side—and the needle is inclined medially enough to reach the median plane about 1½-1¾ inches from the skin, and upwards enough for its slope to be slightly steeper than that of the upper margin of the spine.

be impinging on the upper boundary of the lamina of the lower vertebra, for only in this situation does ligamentum flavum overlie bone (Fig. 80). The needle should be partially withdrawn, the point directed slightly upwards and then pushed in again.

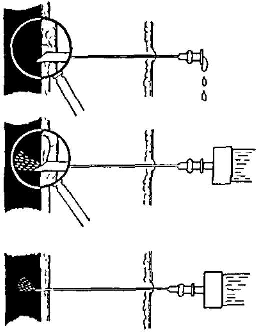

FIG. 75

When cerebro-spinal fluid flows, the needle, particularly if it has a long bevel, should be pushed slightly onwards to ensure that the bevel lies wholly within the dura. If the dura is incompletely penetrated, any solution injected will be deposited partly outside the dura (Fig. 75 centre).

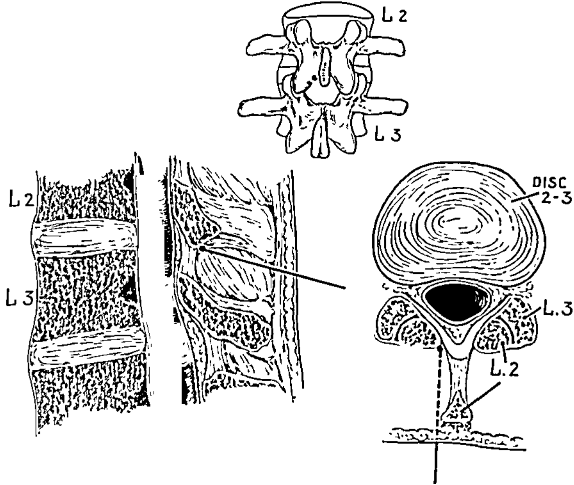

Fig. 78

The skin is penetrated to the left of the median plane and just below the lower margin of the spine of L.2. Even though the skin puncture is almost at the top of the gap between the two spines, the ligamentum flavum would have been pierced if the needle had been directed straight forwards and not *slightly* upwards, or if it had been inclined slightly medially.

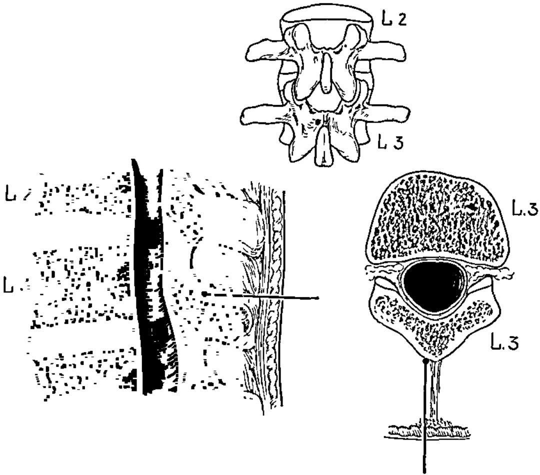

FIG. 77

The site of entry of the needle through the skin is good, but the point has not been directed upwards to miss the lamina of the lower vertebra. In fact, the needle has been thrust straight forwards and hits the left lamina just where it fuses with its opposite number to form the base of the spine, and below the limit of the attachment of the ligamentum flavum on the posterior aspect of the lamina.

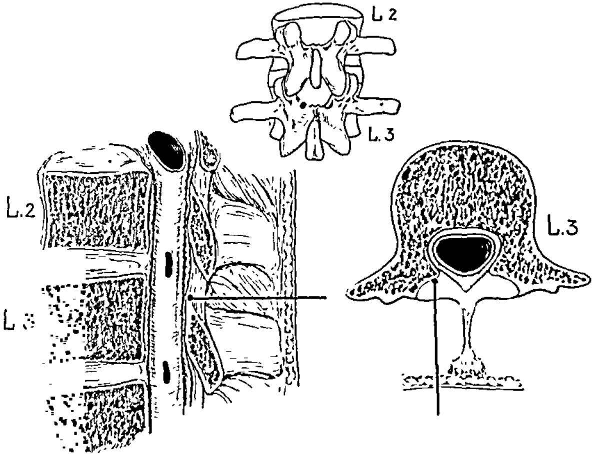

FIG. 80

Here the needle pierces the skin at a level corresponding almost to the middle of the gap between the two spines, but too far to the left. The needle has been pushed directly ahead and hit the left pedicle of L.3, just where it becomes continuous with the lamina. If it had been directed slightly upwards and/or medially all would have been well. In any event the anaesthetist will probably feel the tip of the needle penetrate the ligamentum flavum before it is held up by bone. This is a sure sign that the needle is directed just too low, since the ligament is attached to the posterior aspect of the superior margin of the lamina of the lower vertebra. All that is necessary is partly to withdraw the needle, tilt it slightly upwards and re-insert.

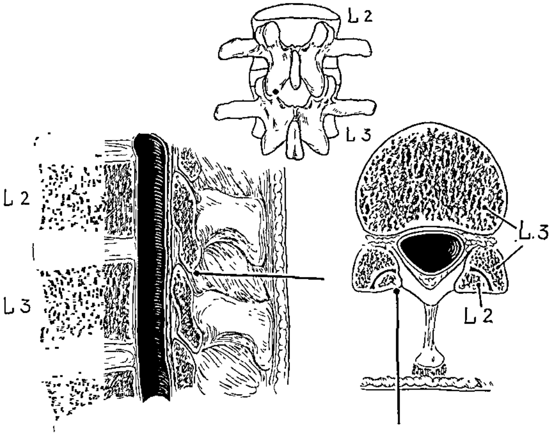

FIG. 79

The needle has pierced the skin just below the lower border of the spine of L.2, but allowance has correctly been made for this by keeping it in the horizontal plane. The error lies in the fact that although the skin is entered well to the left of the *supraspinous ligament*, the needle has been pushed straight ahead and strikes the inferior articular process If the needle is withdrawn and directed slightly medially to compensate for the lateral start, lumbar *puncture* will present no difficulty.

Lusk[2] points out that abnormalities in the form of a firm attachment of the arachnoid to the conus medullaris and/or nerve roots of the cauda equina are not uncommon. It is possible that the very slow but nevertheless sure dripping of fluid is due to the needle, after it passes through the dura, entering a loculus which communicates through a very small opening with the general subarachnoid cavity. This would account, too, for the ineffectiveness of aspiration. If for one reason or another the anaesthetist decides to make the best of things as they are, he should inject a considerably larger dose of local anaesthetic solution than he otherwise would. In this way, despite the mechanical obstruction and rapid absorption into local venous plexuses, enough may find its way to the appropriate nerve roots to provide a satisfactory field of operation. After injection the plunger should be kept depressed for some time with the needle *in situ* to prevent reflux of fluid, locally under considerable pressure, through the hole in the dura into the extradural space.

Spinal Needle Director

A spinal needle director is a short, robust outer needle designed to be inserted through the skin so that an exceptionally fine inner needle, passed through its lumen, can be used for lumbar puncture without fear of bending. There is much to be said for a director. One was illustrated and described by Corning[3] as long ago as 1894, only three years after Quincke's classical description of the technique of lumbar puncture, but the article seems to have attracted no attention and I have been unable to find anything further about this useful little piece of apparatus in the literature until 1928, when Sise[4] wrote about his introducer or director.

A director is particularly useful when the anaesthetist aims at keeping to the median plane throughout, for the direction of the powerful director will not be deflected by the tough supra and interspinous ligaments. A skin wheal is raised and the director, with stilette in place, is thrust through the superficial resistant structures for about an inch towards the interlaminar space. The stilette is withdrawn and, provided that the director is properly sighted, a fine lumbar puncture needle introduced through the lumen has now to overcome only the slight resistances offered by the ligamentum flavum and dura. The very fine lumbar puncture

Dry Puncture

The first thing to be considered under this heading is the so-called "dry tap." Here resistances similar to those offered by the ligamentum flavum and dura may be felt, but cerebro-spinal fluid does not flow. Despite this, the anaesthetist may assert that he is satisfied the point of the needle lies within the dura. In these and similar trying situations in anaesthetics generally there is a temptation and a tendency to blame the unfortunate patient for some abnormality which exonerates the anaesthetist from any blame for failure. It has been suggested that the needle penetrates the dura only to enter an area devoid of cerebro-spinal fluid. It is reassuring that these anomalous cases are encountered with greater frequency during one's novitiate, and that care and experience decrease their number. There is, however, one well recognised exception. If a second lumbar puncture is carried out to investigate the cause of a post lumbar puncture headache, a very low pressure of cerebro-spinal fluid, or even a true dry tap is commonly recorded.

Poor Flow

Occasionally puncture of the dura is disappointingly rewarded by a few hesitant drops of cerebro-spinal fluid. This may be due to a component of the cauda equina lying against the bevel of the needle, blocking it. If the needle is rotated, or pushed a little further in, or slightly withdrawn, the flow may be improved. Nevertheless, sometimes these obvious manoeuvres do not improve matters. Fluid (*e.g.*, a local anaesthetic solution) can be injected freely, but attempts at aspiration are unsuccessful. Various unconvincing explanations are given for this state of affairs, but the fact remains that if a spinal anaesthetic solution is now injected in the usual way, there is a high probability that the extent of the resultant analgesia will be disappointing *If fluid does not drip freely, or is not easily aspirated, the anaesthetist is strongly advised to withdraw the needle and try another space.* This decision is hard to make when difficulty has been encountered in making a dural puncture at all. An unsuccessful attempt may already have been made and the anaesthetist is sorely tempted to rest on his laurels when a few drops of cerebro-spinal fluid issuing from the needle acclaim that the fault is no longer his

needle have to be steadied by the operator's fingers as is the case when a fine needle is introduced without the support of a director.

Perhaps the greatest value of a director is in the elderly patient whose lumbar vertebrae are fixed slightly in extension and the size

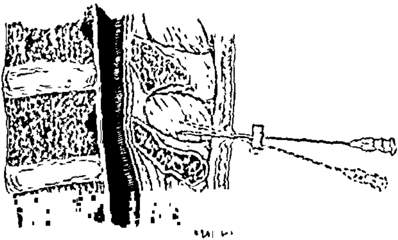

FIG. 83

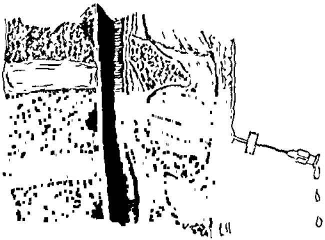

FIG. 84

of whose interlaminar foramina is possibly still further reduced by *osteo-arthritis*. Here on occasions, the needle seems to encounter bone in whichever direction it is thrust. If a director is not used, one frequently sees the anaesthetist repeatedly handling the skin

needle which a director makes practicable leaves only a very small hole in the dura through which seepage of cerebro-spinal fluid subsequently can take place; for this reason many regard the use of a director as a prophylactic against post-lumbar puncture headache.

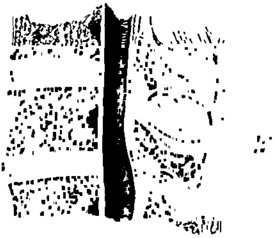

FIG 81

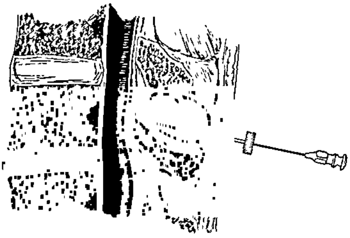

FIG. 82

The director is probably an added safeguard against infection being carried to the subarachnoid space. It pierces the epidermis so that no part of the spinal needle subsequently directed through it comes into contact with the skin. Neither does the shaft of the

the lumen of the director. The thumb and forefinger of the left hand now alter the aim of the director, and a fresh attempt at hitting the target is made by pushing in the lumbar puncture needle gently. Several attempts may be made without causing appreciable damage.

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[4] Sise, L. F. (1928). *J. Amer. med. Ass.* 91, 1186.
[5] Lundy, J. S. (1942). *Clinical Anaesthesia*, p. 257, Fig. 110 (k). Philad.

7

over the spines to verify the landmarks, and the shaft of the needle when re-inserting it. These manoeuvres, particularly in the presence of local haemorrhage, jeopardise asepsis and are to be discouraged. If a director is used, repeated attempts at dural puncture can be made without the anaesthetist touching the skin or the point or shaft of the needle; and if a little haemorrhage does take place through the needle, it can be withdrawn and replaced by a fresh one without making another skin puncture.

After a skin wheal has been raised, the point of the director should not be pushed in for more than an inch through the skin, and it is important that this depth should not be exceeded in thin

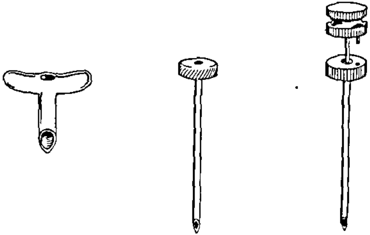

FIG. 85
Spinal needle directors. Corning[3] (a), Sise[4] (b), and Lundy[5] (c).

subjects because in these the dura can be surprisingly superficial. So much so that on more than one occasion I have seen cerebrospinal fluid pour through a director, which inadvertently has been pushed in until it pierced the dura. When the director is in place, the stilette is withdrawn and replaced by the lumbar puncture needle which is pushed on tentatively. If the director is skilfully or fortunately aimed, all is well and the needle passes uneventfully through the ligamentum flavum and extradural space into the dural sac. In this case the procedure has been as straightforward and easy as the textbook illustrations make it appear. If, however, bone is encountered (Fig. 82), the needle is withdrawn until it lies within

4. *Barbotage.*

Respiration and heart beat impulses can be detected on a manometer when the cerebro-spinal fluid pressure is being read; the vibrations set up by these, however, play a negligible part in the distribution of any local anaesthetic injected. The effect of *diffusion* also is so slow that it does not even call for consideration.[1]

Manufacturers offer their solutions for spinal analgesia in a wide variety of concentrations and a wide range of specific gravities. Thus, for example, if an anaesthetist wishes to administer 10 mg. of Nupercaine, he can do so either by giving 2 cc. of 1/200 solution or 15 cc. in a dilution of 1/1,500; and there are intermediate concentrations available. Spinal anaesthetic solutions are classified in three groups as hyper-, iso-, or hypobaric, depending on whether they are heavier, of equal weight, or lighter than cerebro-spinal fluid. The specific gravity of cerebrospinal fluid shows remarkably little variation in different subjects; at body temperature it is practically 1·0003 relative to water at 4°C. (see p. 117). The specific gravities of spinal anaesthetic preparations range from 1·080 in the case of Chaput's solution of Stovaine down to 1 000 in the case of Spinocaine.

The specific gravity of the spinal anaesthetic solution depends on what is added to the distilled water. The additions are the local anaesthetic salt, and either sodium chloride or glucose, and in a few preparations, alcohol. If the local anaesthetic salt alone were added, the specific gravity of the solution would necessarily become greater than that of the solvent, but in some cases not much greater. For instance, Nupercaine is such a powerful agent that only a little is needed to produce spinal analgesia, so that by itself the weight of Nupercaine added influences the specific gravity of a spinal anaesthetic solution but little. If 10 mg. is added to 2 cc. distilled water, the specific gravity of the solution becomes 1·004, if the same amount is added to 20 cc. the specific gravity of the solution, to the third decimal place, is the same as that of water. Procaine is a much less powerful drug, and an approximate equivalent in anaesthetic effect is 200 mg. If this weight of procaine is added to 2 cc. distilled water the specific gravity becomes 1 03, and if added to 20 cc., 1·007.

If a solution is made really light or heavy (relative to cerebrospinal fluid) the direction of its spread throughout the subarachnoid

CHAPTER VII

Distribution of Analgesic Solution

WHATEVER nerve roots it is desired to anaesthetise, it is accepted practice for the reasons given on page 28 to introduce the needle into the subarachnoid space and inject the anaesthetic solution in the lumbar region, usually between L.2-3.

If the site of operation is leg or perineum, no difficulty arises about conveying the anaesthetic solution to the nerve roots to be rendered analgesic; the needle already lies in their midst where they form the cauda equina just below the conus medullaris. A local anaesthetic injected here will necessarily produce analgesia below this level, just as would transection of the nerves.

If, however, the field of operation is the upper abdomen or the thoracic cavity, the problem arises as to how the mid and even upper thoracic nerve roots can be anaesthetised in the subarachnoid space. It is true that spinal punctures can be made at these high levels. This direct and heroic approach to the thoracic roots had its supporters many years ago,[1] but it never achieved wide popularity and now happily has fallen out of favour altogether. Reference to figure 7 shows that here the approach of the needle to the dura is not simple owing to the steep downward slope of the spinous processes. With a little practice this difficulty is easily overcome in the upper and lower thoracic regions, but not quite so readily in the case of the middle four thoracic vertebrae whose spines point almost vertically downwards. Quite apart from this minor technical obstacle there is the overriding consideration that if the needle is inserted too far the spinal cord itself may be injured.

If an orthodox lumbar puncture is made, the anaesthetic solution can be distributed from the site of puncture to any desired level by any of the following means: —

1. *Gravity.*
2. *Volume displacement.*
3. *Turbulent currents* which are set up when the solution is injected rapidly into the dural canal, and closely allied to these.

4. *Barbotage.*

Respiration and heart beat impulses can be detected on a manometer when the cerebro-spinal fluid pressure is being read; the vibrations set up by these, however, play a negligible part in the distribution of any local anaesthetic injected. The effect of *diffusion* also is so slow that it does not even call for consideration.[2]

Manufacturers offer their solutions for spinal analgesia in a wide variety of concentrations and a wide range of specific gravities. Thus, for example, if an anaesthetist wishes to administer 10 mg. of Nupercaine, he can do so either by giving 2 cc. of 1/200 solution or 15 cc. in a dilution of 1/1,500; and there are intermediate concentrations available. Spinal anaesthetic solutions are classified in three groups as hyper-, iso-, or hypobaric, depending on whether they are heavier, of equal weight, or lighter than cerebro-spinal fluid. The specific gravity of cerebrospinal fluid shows remarkably little variation in different subjects; at body temperature it is practically 1·0003 relative to water at 4°C. (see p. 117). The specific gravities of spinal anaesthetic preparations range from 1·080 in the case of Chaput's solution of Stovaine down to 1·000 in the case of Spinocaine.

The specific gravity of the spinal anaesthetic solution depends on what is added to the distilled water. The additions are the local anaesthetic salt, and either sodium chloride or glucose, and in a few preparations, alcohol. If the local anaesthetic salt alone were added, the specific gravity of the solution would necessarily become greater than that of the solvent, but in some cases not much greater. For instance, Nupercaine is such a powerful agent that only a little is needed to produce spinal analgesia, so that by itself the weight of Nupercaine added influences the specific gravity of a spinal anaesthetic solution but little. If 10 mg. is added to 2 cc. distilled water, the specific gravity of the solution becomes 1·004, if the same amount is added to 20 cc. the specific gravity of the solution, to the third decimal place, is the same as that of water. Procaine is a much less powerful drug, and an approximate equivalent in anaesthetic effect is 200 mg. If this weight of procaine is added to 2 cc. distilled water the specific gravity becomes 1 03, and if added to 20 cc., 1·007.

If a solution is made really light or heavy (relative to cerebrospinal fluid) the direction of its spread throughout the subarachnoid

space can be controlled by gravity. Pitkin's solution or Spinocaine, a preparation which includes 10 per cent. procaine and 15 per cent. alcohol w/w dissolved in normal saline, has a specific gravity of 1·000. The alcohol is included solely to make the mixture lighter than cerebro-spinal fluid, so that by posturing the patient suitably it will rise in the subarachnoid space to the nerve roots which it is desired to anaesthetise. Chaput's solution of 10 per cent. Stovaine dissolved in 10 per cent. saline, on the other hand, is very heavy (specific gravity 1 080) and this factor makes the direction of its flow in the cerebro-spinal fluid easily controllable.

Pitkin's solution, largely because of its alcohol content, and Chaput's because of the high salt concentration, both have a tonicity approximately twelve times that of blood plasma or cerebro-spinal fluid. This may be of little importance, but it is reasonable to suppose that a solution of lower tonicity is even less likely to be harmful to nerve roots or cord. Present-day heavy solutions of spinal anaesthetics (*e.g.*, heavy Nupercaine, Xylocaine) are made by dissolving the drug in 5 per cent. glucose. Such a solution has a specific gravity of approximately 1·025, and this is easily high enough to ensure its spread in the subarachnoid space in the direction the anaesthetist wishes; it has the added advantage that it is less hypertonic.

In the widely used " light " Nupercaine, the drug in a concentration of 1/1,500 is dissolved in half strength physiological saline. The solution is hypotonic, and at room temperature has a specific gravity of 1 0028 relative to water at 4°C.[3] so that it is a trifle lighter than cerebro-spinal fluid at body temperature. In my opinion the " lightness " of this preparation has been stressed too much: the spread of the drug within the dura is determined by the large volume of fluid injected and not by any minute difference in the specific gravities of the two fluids.

The wide range both in dilutions and specific gravities in which a given weight of spinal anaesthetic drug is available allows the anaesthetist to indulge his fancies as to how the drug can best be conveyed to the nerves of the area to be rendered analgesic.

Gravity

Probably the most accurate way of limiting the spread of a local analgesic agent to the nerve roots it is desired to anaesthetise is to use the drug in a solution of small volume and high specific

gravity. The small volume ensures that the effect of volumetric displacement discussed in the next section is negligible, so that in practice the method resolves itself into one of gravity control.

The problem is one of hydrostatics. The vertebral canal has various slopes the inclination of which can be influenced by altering the posture of the patient, and/or the tilt of the table. The specific gravity of cerebro-spinal fluid housed in the vertebral canal is, say, 1·002 and a much heavier solution of local anaesthetic introduced into the dura follows the law of gravity and tracks downwards. Adsorption or "fixation" by the nerve roots takes place *en route*, and any remainder pools at the bottom of the slope.

The distribution resulting from the introduction of a heavier solution into the subarachnoid space was first demonstrated by Barker[4] in a "glass spine"—a glass tube curved to reproduce the shape of the vertebral canal (Fig. 86). A small rubber-covered inlet in the concavity of the lumbar curve allows the introduction of a needle. The "glass spine" is filled with a weak saline solution having a specific gravity of 1 002 to represent the cerebro-spinal fluid. A few drops of methylene blue are added to the anaesthetic solution to be injected so that its spread within the glass spine can be followed easily (Figs. 86 and 98).

For any operation on the legs or perineum, it matters little whether the injection of a "heavy" solution is given with the patient sitting up or on his side. The needle is inserted, say, between L.2-3 and if the solution is injected at all briskly it will spread across the subarachnoid space at this level anaesthetising the whole of the cauda equina (Figs. 87 and 96). For an operation confined to the distribution of the sacral nerves there is something to be said for giving the injection with the patient sitting up. For haemorrhoidectomy a small volume such as 0 6 cc. injected slowly trickles down to the end of the dural sac. If the fourth and fifth sacral nerves only are affected a very circumscribed area of anaesthesia around the anus results. If slightly more extensive analgesia is required, as for operations on the perineum a dose of 1 cc. injected with slight force meets the occasion by ensuring that the distribution is widespread enough to involve all the sacral nerves.

For an abdominal operation, all the injected spinal anaesthetic solution should be directed upwards towards the intercostal nerves

space can be controlled by gravity. Pitkin's solution or Spinocaine, a preparation which includes 10 per cent. procaine and 15 per cent. alcohol w/w dissolved in normal saline, has a specific gravity of 1 000. The alcohol is included solely to make the mixture lighter than cerebro-spinal fluid, so that by posturing the patient suitably it will rise in the subarachnoid space to the nerve roots which it is desired to anaesthetise. Chaput's solution of 10 per cent. Stovaine dissolved in 10 per cent. saline, on the other hand, is very heavy (specific gravity 1·080) and this factor makes the direction of its flow in the cerebro-spinal fluid easily controllable.

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In the widely used "light" Nupercaine, the drug in a concentration of 1/1,500 is dissolved in half strength physiological saline. The solution is hypotonic, and at room temperature has a specific gravity of 1 0028 relative to water at 4°C.[3] so that it is a trifle lighter than cerebro-spinal fluid at body temperature. In my opinion the "lightness" of this preparation has been stressed too much: the spread of the drug within the dura is determined by the large volume of fluid injected and not by any minute difference in the specific gravities of the two fluids.

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Gravity

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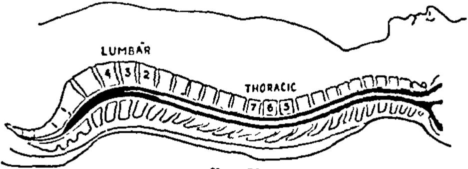

FIG. 88

it is desired to anaesthetise. Two important landmarks should be noticed in figure 88. The summit of the lumbar convexity is the 3rd lumbar vertebra—the level at which lumbar puncture is commonly performed. The deepest point in the thoracic concavity is T.5-6, and at this level the intercostal nerve which issues supplies:

1. The uppermost branch of the splanchnic nerves, and
2. The skin over the xiphisternum and the uppermost part of the abdominal wall.

If the nerves between the site of lumbar puncture and T.5-6 are anaesthetised, the whole of the abdominal wall will be rendered analgesic and the sympathetic nerve supply of the viscera will be interrupted (Fig. 43).

If lumbar puncture is made on an average patient lying on his side on a horizontal table, the injected "heavy" fluid will at first lodge around the site of puncture. If now the needle is withdrawn, and the patient told to roll over on to his back, it will be found that the injected fluid remains for a very short time at the summit of the lumbar convexity, after which it flows down the two slopes in different directions. That part of the solution which runs down into the sacral hollow is completely wasted as far as providing anaesthesia for abdominal surgery is concerned.

If the puncture is made between L.3-4 or L.4-5, the anaesthetic solution will enter the subarachnoid space opposite the lower lumbar vertebrae, and when the patient rolls on to his back, the bulk of it will gravitate into the sacral hollow away from the direction it was intended to follow. Even worse is the result if the patient is made to sit up for lumbar puncture, and the heavy anaesthetic solution injected before he is told to lie down. The heavy solution sinks rapidly so that even if the patient lies down

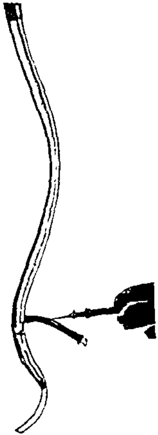

FIG. 86

FIG. 87

FIG. 86 A glass "spine," held upright, is filled with a salt or glucose solution having the same specific gravity as cerebro-spinal fluid. Any standard heavy spinal anaesthetic solution, here coloured with methylene blue for contrast purposes, introduced into the column of fluid sinks at once. There is no upward spread.

If, when the patient is sitting, the heavy solution is injected and if the point of n the centre of the d may become anaesthetised A butterfly area of analgesia around the anus results For haemorrhoidectomy this technique is a refinement of the one illustrated in Fig. 87, but has no real advantage over it.

FIG. 87. If a heavy solution is injected a little more rapidly the whole of the cauda equina will be affected. The *solution commences to sink at once and even if* the patient lies down immediately, the effect will be confined to the lumbar and sacral nerves. If analgesia of the abdominal wall is aimed at, it is obvious that this technique is faulty.

The inclination of the vertebral column is a factor of great importance in determining the spread of a heavy spinal analgesic solution.

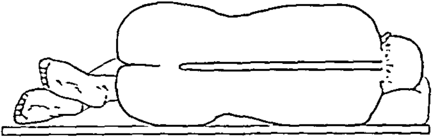

Fig. 89
When the average patient is in the lateral position ready for lumbar puncture, the vertebral column is more or less horizontal.

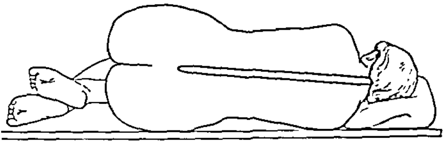

Fig. 90
In women, however, the column may incline downwards towards the head.

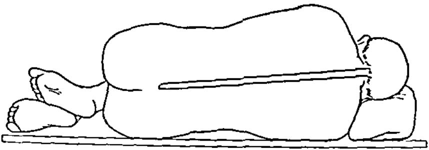

Fig. 91
In men the inclination may be downwards towards the coccyx. (*After Mushin.*)[1]

immediately after the needle is withdrawn, the major portion will have passed into the sacral hollow and be unable to play any part in providing analgesia of the abdominal wall and contents.

The technique of using a "heavy" solution of a spinal anaesthetic for an abdominal operation is exceptionally easy. The patient lies on the side in which the incision is to be made, or on either side if the incision is to be midline. The whole table is now tilted until it is quite obvious to the observer's eye that the patient's vertebral column slopes downwards towards his head. In the case of the male with narrow hips and broad shoulders (Fig. 91), a considerable tilt of the table will be necessary, less so in the case of the female with broad hips and narrow shoulders where a mild downward slope towards the head already exists. The angle to which the table should be tilted varies, therefore, from patient to patient. Precision is unnecessary, but the angle must be sufficient for it to be quite clear that the slope of the line joining the tips of the spinous processes is downwards towards the head. Not till then is the back flexed and lumbar puncture performed. The heavy anaesthetic solution injected will at once start to travel cephalwards (Fig. 100).

As soon as the injection is finished, the needle is withdrawn and the patient rolled on to his back. The heavy anaesthetic solution continues its downward course into the thoracic hollow. On its journey some of the drug is adsorbed or "fixed" by the nerve roots, and some absorbed by the venous plexuses which abound there.* These two processes are fairly constant, so that in practice the vertebral level reached by the drug depends on the quantity injected. If the amount is small, the downward flow soon peters out, automatically limiting the level of analgesia. If the volume of injected solution is large, any which remains unabsorbed or unadsorbed will continue its downward trek to the most dependent part of the thoracic curve, which because of the slope of the table will now be about T.4-5. Here any remaining local anaesthetic solution will pool. Just as surely as the heavy solution flows *down* one side of the thoracic curve, so it will not flow *up* the other and over the cervical vertebrae towards the vital centres. Such a reversal of the natural forces is out of the question, so that it is entirely unnecessary to give the patient an extra pillow to guard against a fanciful upward spread of heavy fluid.

[*Continued on p. 116*

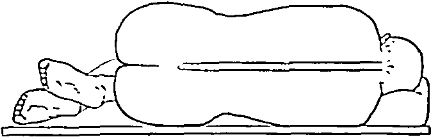

Fig. 94

Fig. 95

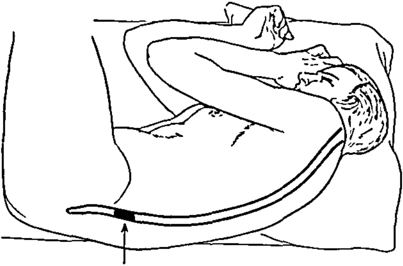

Fig. 96

FIG. 92
The vertebral column is horizontal.

FIG. 93
If a heavy spinal analgesic solution is to be used for abdominal surgery, the table must be tilted until, as in this illustration, it is obvious that a line joining the spinous processes slopes downwards towards the head

Correct technique when using a heavy solution for spinal analgesia.

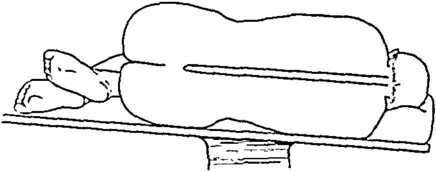

FIG. 99
The table is tilted until it is quite obvious that the vertebral column inclines downwards towards the head.

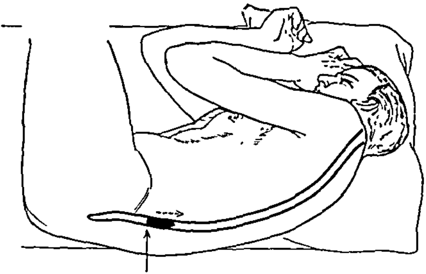

FIG. 100
The precise site of injection is immaterial. The solution at once runs down the incline. Contrast with Fig. 96.

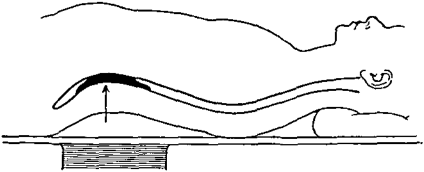

FIG. 97

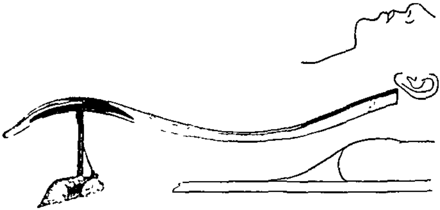

FIG 98

These illustrations show the result of injecting a heavy analgesic solution when the vertebral column is horizontal.

FIG 94. The dural canal is horizontal

FIG. 95. The patient in position for lumbar puncture—viewed from above.

FIG 96. The injected solution remains at the site of injection, between L 2-3.

FIG. 97. When the patient rolls over on to his back the height of the lumbar convexity corresponds to the level L.2-3 The heavy solution now runs down both slopes. The part running into the sacral concavity is completely wasted as far as providing analgesia for abdominal surgery is concerned.

FIG. 98. The experiment carried out in a "glass spine" filled with saline (s g. 1·0003) to represent cerebro-spinal fluid. The heavy analgesic solution is coloured with methylene blue.

During its downward course some of the analgesic solution is "fixed" by the nerve roots, some is absorbed into the veins of the spinal cord. The level reached by the analgesic drug depends on the volume of solution injected. See Figs. 103, 104 *and* 105.

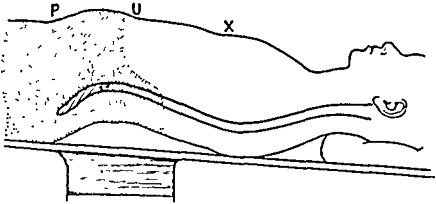

FIG. 103

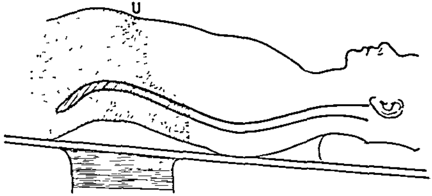

FIG. 104

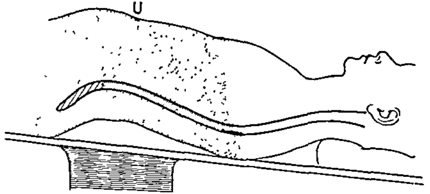

FIG. 105

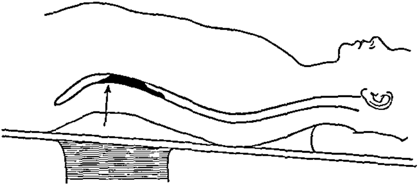

FIG. 101
When the patient turns on to his back the solution flows on towards the thoracic concavity.

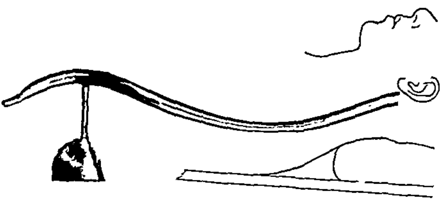

FIG. 102
The experiment carried out with a "glass spine."

FIGS. 103, 104, 105

FIG. 103—1 4 cc. of a standard heavy solution has reached the 11th thoracic nerve roots anaesthetising the abdominal wall to just below the umbilicus.

FIG. 104—1 6 cc of the solution reaches the 9th intercostal nerve roots and provides admirable analgesia, for example, for Caesarean section.

FIG. 105—If 2 cc. of solution is injected some of it will reach the thoracic concavity which, because of the slope of the table, is at the level of about T.5. any excess of solution will pool here, and cause no harm. Analgesia high enough for any abdominal operation is assured.

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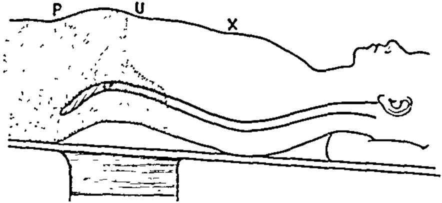


FIG. 103

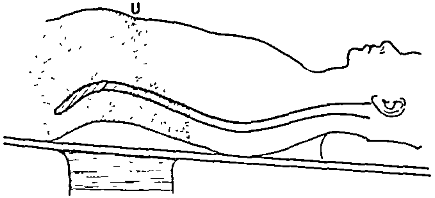


FIG. 104

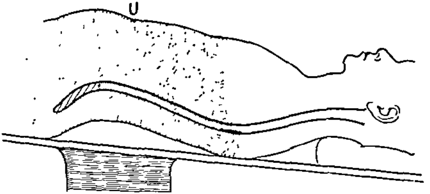


FIG. 105

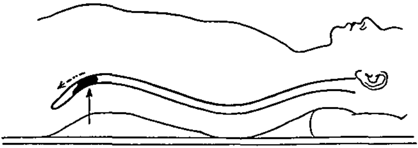


FIG. 106

FIG. 106. A heavy al canal low down (L.4-5) when ves particularly disappointing the patient rolls on to his bacl ierced is on the sacral slope of the lumbar convexity. The solution runs into the sacrum: little, if any, runs cephalwards to reach even the lowest intercostal nerves.

The volumes of any of the standard heavy solution (*e.g.*, Nupercaine or Xylocaine) recommended for an abdominal operation in an average adult are:

herniotomy	1·2 cc.
appendicectomy	1·5 cc.
prostatectomy or Caesarean section .	1 6 cc.
upper abdominal operations . . .	2 cc.

From the foregoing it will be seen that for any operation below the level of the diaphragm a heavy solution of local anaesthetic can be made to give excellent results. I have no personal experience of truly light solutions—*i.e*, those to which alcohol has been added *to make them less dense than cerebro-spinal fluid.* I have seen such solutions used with good results, but not better than when heavy solutions have been employed for similar operations.

The technique described by Lake[7] could, with some justification be described here, but it is dealt with in the next section.

Volumetric Displacement

Under this heading I particularly want to consider the widely used solution of 1/1,500 Nupercaine in half strength physiological saline. The preparation is described as "light" and "hypo-baric," by the makers, but there is no evidence to show that the solution

at room temperature is less dense than the cerebro-spinal fluid in which it is to be injected. It would be interesting to know wh changes, if any, chemists would make in the specific gravity if th set out to make this solution isobaric.

It is easy to see how the inaccurate term "light" came in use. The 1 1,500 Nupercaine solution was introduced by Howa Jones[4] over a quarter of a century ago, and further popularised b Etherington-Wilson[6] and Lake.[7] Presumably because of the lar volume used they do not seem to have thought of injecting th solution at room temperature, as is now commonly done. Th warmed it to body temperature, and the specific gravity th becomes less than that of the cerebro-spinal fluid into which it injected. The table below shows that it is only when the soluti is warmed—a practice now rarely followed—that it is made light than the cerebro-spinal fluid at body temperature. The table mak it clear, too, that the figure given as the specific gravity of a fluid is meaningless unless the temperature of the fluid is stat as well as the standard to which it is referred: and that it is poin less to compare the specific gravities of two solutions (*e.g.*, Nupe caine and cerebro-spinal fluid) unless both figures refer to the sa standard.

Nupercaine Solution at	*Standard—Water at:* 4°C.	15°C.	20°C.	37°C.
15°C.	1 0029	1 0038	—	—
20°C.	1 0020	1 0029	1 0038	—
37°C.	0 9969	0 9978	0 9987	1 0036
Cerebro-spinal fluid at 37°C.*	1 0003	1 0011	1 0021	1 0070

Specific gravities of 1/1500 Nupercaine in half strength physiological saline, and of cerebro-spinal fluid, expressed relative to water at various temperatures.

* For aqueous solutions containing inorganic salts in minute amounts—a cerebro-spinal fluid fits into this category—the rate of expansion with tempe ture is essentially the same as that of water.[8]

1

The *specific weight* of a liquid at a given temperature is the weight, in grams, of 1 cc. of the liquid. The *specific gravity* of a liquid at a given temperature is its specific weight divided by the specific weight of water at some stated temperature. For example, if the specific gravity of a solution is designated 20°/4° it means that the temperature of the solution is 20°C. and that of the water to which it is referred is 4°C. In scientific publications water at 4°C. is the customary choice as a reference standard since its specific weight is 1·000 gm/cc.

Another method of expressing the specific gravity of a solution is to refer the specific weight of the solution at a given temperature to that of water at the same temperature. Thus, to say that the sp.gr. of Nupercaine solution 37°/37° is 1·0036, is a convenient method of stating that Nupercaine solution at 37°C. is 36/10,000 times heavier than water at the same temperature. Some find it more convenient in their particular work to express the specific gravity of a solution at a temperature nearer room temperature, say at 20°C., relative to water at the same temperature. This figure can be determined by filling a flask of known weight with the solution at 20°C. and then determining the weight of the liquid on the balance. The flask is now filled with water at the same temperature and its weight is also measured. The ratio of the two weights is the specific gravity of the liquid 20°/20°.

The specific gravity of cerebro-spinal fluid cannot be given with complete assurance. Some of the estimates have been made by clinicians who, speaking generally, are not fussy when it comes to the third or fourth decimal place. There is some doubt whether the specific gravity is virtually uniform in different subjects or whether it varies. Etherington-Wilson[11] reports that the specific gravity of the fluid, at body temperature, in 314 consecutive patients was remarkably constant between 1·003 and 1·004, but he does not state the standard to which the figure is referred. Levinson[12] lists thirteen authorities who show an over-all variation in specific gravity between 1 001 and 1 010, but in only one case is the temperature of the cerebro-spinal fluid given, and in none is the standard of comparison mentioned. The first accurate report my colleague, Dr. Epstein, can find on this subject is by a research chemist, R. V. Stanford[13] who examined, with meticulous care, a series of cerebro-spinal fluids at a large mental hospital. The

investigation was carried out with the fluids at 25° C., and the specific gravity was referred to water at 4° C. In a small group of ten samples from epileptic patients he found what he describes as "an extraordinary wide range" from 1 00135 to 1 00610. The mean of his total of seventy-three samples is 1 0015. This mean figure has been strikingly confirmed thirty years later in a thorough investigation on 150 healthy young men. In this series[16] the specific gravities (25° 4°) lie within the range of 1 0032 to 1 0052, with a mean value of 1 0040. This last figure is the basis for the calculated values in the last line of the table on page 117, which gives the specific gravity of cerebro-spinal fluid at 37° C., referred to water at 4° C., as 1 0003.

At room temperature "light" Nupercaine is in fact somewhat heavier than cerebro-spinal fluid at body temperature, but this difference occurs in the third decimal place, and is of negligible importance as far as gravitational effect is concerned. The specific gravity of heavy spinal anaesthetic solutions made up in 5 per cent. glucose is generally given as 1 025. The difference between this and the specific gravity of cerebro-spinal fluid is shown in the second decimal place, and is of practical significance. In the case of the heavy solution the temperature of the water to which the specific gravity refers is of no importance to the anaesthetist. Whether this figure of 1 025 is relative to water at 4° C., to water at 15° C., or to water at its own temperature (if other than 15° C.), is quite immaterial, because in any case the figure is high enough to show that the solution is much heavier than cerebro-spinal fluid at body temperature: and it will sink rapidly when injected.

The anaesthetist is advised to accept the view that the specific gravities of "light" Nupercaine at room temperature, and of cerebro-spinal fluid at body temperature are so close that gravity plays no part in the spread of the solution injected as it stands. It is the large volume used and not any subtle difference in specific gravity which determines the extent of the distribution. Estimations of the volume of cerebro-spinal fluid (Fig. 30) from the end of the dural sac to any given vertebral level vary considerably,[14] and even though it is a generous estimate, I am assuming the volume up to T.6 to be 18 cc. If, therefore, 18 cc. of 1/1,500 Nupercaine, whatever its specific gravity, is injected in the lumbar region, it will have to occupy space at the least to T.6. And this does not

allow for the cerebro-spinal fluid already occupying the space, but, on the other hand, it does not take into consideration rapid absorption into the veins because of the temporarily increased subarachnoid pressure.

As we have seen, when "light" Nupercaine was first used it was in fact rendered lighter than cerebro-spinal fluid by warming it just before it was injected. Howard Jones[7] in his original article, says that before injection the solution should be "just cooled to body temperature from recent boiling." The solution is now less dense than cerebro-spinal fluid,—and it is this which made it appear advisable to introduce an otherwise unnecessary complication into his technique. He emphasised the desirability of placing the patient first in the prone position for five minutes so that the light solution would rise to the posterior nerve roots and so ensure freedom from pain. Only after this was the patient rolled over on his back. Quite apart from the undesirability of turning a big, fat, or ill patient on to his face, the second turn from the prone to the supine position is often a difficult and disturbing one, since by this time the patient is paralysed. If, instead of injecting 15 cc. of warmed Nupercaine and subjecting the patient to undesirable turns, the same volume of solution at room temperature is given and the patient rolled straight over into the dorsal decubitus ready for operation, practically identical results are obtained.

Similar considerations apply to the spread of the local anaesthetic solution in the Etherington-Wilson technique.[9] The injection of warmed Nupercaine is given when the patient is sitting upright; and he is kept in this position for a given number of seconds, timed accurately with a stop-watch, to make sure that the light solution rises to the desired levels. It is true that owing to the vertical position being maintained a slightly smaller volume of solution suffices, but the economy is of no practical importance. The same nerve segments would be anaesthetised by injecting a slightly larger volume of solution at room temperature, and placing the patient at once in the position in which he is going to be operated on. The general toxic effect of the additional 2 or 3 cc. of 1/1,500 Nupercaine is, of course, entirely negligible.

In the technique for abdominal surgery described by Lake,[7] the patient is placed prone, his head and neck are flexed on the thorax, and the table is carefully tilted until the seventh thoracic spinous

Influence of the rapidity of injection on the spread of analgesic solution within the dural canal (see "turbulent currents," p. 124).

The three experiments illustrated on these two pages demonstrate that the spread of an injected solution increases with the rapidity of injection, and that this in turn is facilitated by a needle of large bore and by a syringe with a small diameter—see p. 124

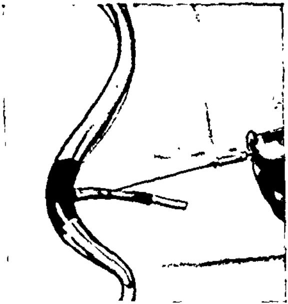


FIG. 107

4 cc. of solution is injected from a 20 cc. syringe through a fine needle. Becaus of the marked resistance offered by the needle the injection takes some fev seconds to make, and the flow is not rapid enough to cause turbulence. No eddie are seen and the solution remains localised around the site of injection.

A "glass spine" containing saline solution to represent cerebrospinal fluid was held horizontal, and heavy Nupercaine solution, coloured with methylene blue, was injected through the rubber inlet. Two needles of different bore, and a 2 cc. and 20 cc. syringe were used. The same thumb pressure was applied in each case to the piston.

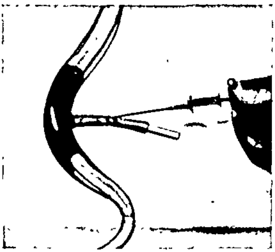


FIG. 108

2·5 cc. of solution is injected from the same syringe through a large bore needle. Much less time is needed to complete the injection. Eddies are seen. Despite the fact that a smaller volume of solution is used than in the previous experiment, the spread is greater.

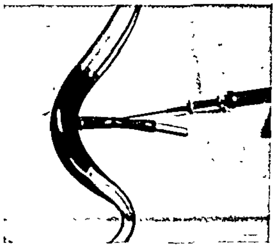
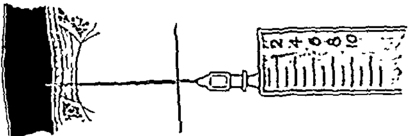


FIG. 109

2·5 cc. of solution is injected from a syringe with a small piston through the same large bore needle. The rate of flow through the needle is rapid, and the eddies and the spread of the solution are more marked than in the previous experiment.

process lies at the summit of the convexity of the spinal column. Lumbar puncture is now carried out and about 8 cc. of 1/1,500 Nupercaine " warmed to about body temperature or a little above " is injected very slowly: the slope of the vertebral column ensures that the light solution will rise to the desired level and no higher. After five minutes the patient is rolled back into the dorsal decubitus ready for operation. The volume of Nupercaine used is small but in my experience the general condition of the patient is no better than when a less involved technique is followed.



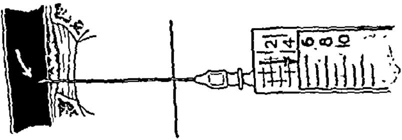


FIG. 110

Top—15 cc. of dilute Nupercaine solution has been injected. The intradural pressure is raised temporarily. *Bottom*.—If the thumb is now removed from the piston several cc. of fluid will be forced back into the syringe.

If 1/1,500 Nupercaine is to be used nothing is gained by warming it. The solution, at room temperature, should be regarded as isobaric; and it can be injected with the patient in any posture, immediately after which he can be placed in position ready for operation. The extent of the spread of the solution depends on the volume injected, and in calculating the dose the following points should be borne in mind. The increase in intradural pressure resulting from the large volume injected increases the rate of

absorption of the solution into the capillaries of the cord. If before injection any considerable volume of cerebro-spinal fluid is allowed to escape, the rate of venous absorption is decreased so that the effect of any given volume of Nupercaine will be more widespread. The local circulation in the young and healthy is more vigorous and in them absorption of Nupercaine into the venous plexuses is more rapid; the original injection should be correspondingly greater. When the injection is completed, the subarachnoid pressure is often temporarily high enough (over 500 mm. water) to force several cc. of fluid back into the syringe (Fig. 110). The plunger should be kept depressed with the needle *in situ* for some thirty seconds, for after this short lapse of time excessive pressure is not obvious. If the needle is withdrawn as soon as the injection of a large volume is finished, there will be a considerable escape through the puncture hole into the extradural space. The following dosage is recommended in adult patients of average build and fitness. For an upper abdominal operation, *e.g.*, gastrectomy, 17 cc.; for Caesarean section or appendicectomy 13 cc.; and for herniotomy 11 cc.

Turbulent currents are set up if an injection is made rapidly enough into the dural canal, and these influence the extent of the spread of the injected solution beyond the site of puncture. Rapid injection is facilitated by a needle of large bore,[15] and a syringe of small diameter[16] (Figs. 108 and 109). With the fine needles now in vogue it is difficult to inject sufficiently rapidly to affect distribution. However, even with the slow currents resulting from the use of fine needles, the spread can be increased by repeating the injection several times. This process, which does not involve an increase of local anaesthetic drug over that given in the original injection, is known as:

Barbotage (from the French, *barboteur,* tame duck, and used in the sense of puddling, dabbling, or stirring up).

The term is applied to the technique by which a local anaesthetic solution is injected into the spinal canal, after which the movement of the piston is reversed and fluid is withdrawn into the syringe. This to-and-fro action of the piston which simulates that of a mechanical pump sets up currents which carry the drug far afield. The extent of the distribution, which is not accurately predictable, is determined by the mass of local anaesthetic drug,

the speed with which the injection is made (see above under "turbulent currents") and the number of times it is repeated. The method was described in 1907,[17] given a name by Le Filliatre[18] and popularised by Labat.[19] Barbotage is an effective method of "ironing out" any waywardness in the distribution of a solution due to the specific gravity, and/or the posture of the patient. Thus Labat allowed cerebro-spinal fluid to drip into an ampoule containing a known weight of procaine crystals, and by employing barbotage distributed the hyperbaric solution to any desired level even with the patient in the sitting position. For a lower abdominal operation 150 mg. procaine is a suitable dose, for an upper abdominal operation 200-250 mg.

A form of extrathecal barbotage, not always appreciated as such, has been used by many.[20] If analgesia of distant nerve roots is aimed at, as for a gall-bladder operation or mastectomy, 7 or 8 cc. of cerebro-spinal fluid is allowed to drip into a receptacle containing the crystals or solution of local anaesthetic drug, and thorough mixing, or extrathecal barbotage, is carried out. This process is sometimes known as "expanding" the anaesthetic solution.[21] When this large volume is re-injected it necessarily spreads over a wide field; the effect is similar to intrathecal barbotage.

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CHAPTER VIII

Headache

HEADACHE is, and always has been, a sequel frequent and disabling enough to intrude itself into any general picture of spinal analgesia. Indeed, prominent reference is made to this unpleasant complication in the first two records of operations carried out under spinal analgesia by Bier[1] and Tuffier,[2] and it cannot be affirmed that the prediction of the latter "the explanation of it will come later" has been completely fulfilled even now after fifty years.

Symonds[3] from observations during operations on the brain under local analgesia, points out that the brain itself is insensitive but that pain is caused by traction on structures which support and anchor it, particularly the dura mater round the base of the brain and the tentorium. Pulling on the blood vessels is also painful. This resembles the state of affairs within the abdominal cavity where, although the main structures are insensitive, pain may be elicited by traction on the anchoring mesentery and blood vessels. He records, too, experiments which show that headache can be caused by anything which increases the amplitude of arterial pulsations within the cranium, *e.g.*, inflammation or febrile conditions, and he believes the symptom to be due to abnormal stretching of the arterial wall. Whatever the primary cause may be, it is probable that the headache which follows a spinal anaesthetic is mediated through one or other of these two mechanisms, and the factors responsible for putting them into action are different in the two cases.

There are three quite distinct causes of headaches after spinal analgesia The first is the continued escape of cerebro-spinal fluid through the hole in the dura into the extradural space. This accounts for the great majority of these headaches; and the complication here has nothing to do with the spinal anaesthetic *per se,* since it is just as likely to follow a simple lumbar puncture. The second cause is the development of an aseptic inflammatory meningeal reaction to the injected solution, and possibly to the introduc-

tion of a minute amount of antiseptic from the skin, a few skin cells, or to a drop or two of blood: and occasionally this reaction is severe enough for the stretched walls of the engorged vessels to cause pain. The third cause, inflammatory reaction to the introduction of organisms, is the rarest, yet the only serious one. Some rise in cerebro-spinal fluid pressure co-exists with the last two causes of headache. It is misleading, however, in these cases to refer to "high pressure" headache, since, as will be seen later, the cerebro-spinal fluid pressure can be raised greatly without causing symptoms.

The indictment of the continued escape of cerebro-spinal fluid as *the* cause of headache after lumbar puncture is convincing. That there must be some loss is self-evident. The pressure within the dural sac is of the order of say 150 mm. water, the pressure in the lumbar extradural space is sub-atmospheric[4]; some escape of fluid, therefore, inevitably occurs after lumbar puncture, and this will continue until the hole becomes occluded. By an ingenious experiment Franksson and Gordh[5] show that in an average case the escape is about 10 cc. an hour. There is plenty of evidence that the hole in the dura takes some time to heal. It is not uncommon to find, at autopsy, that the hole resulting from lumbar puncture many days previously has not healed, but in these cases the reparative processes may have been deficient. During operation for a prolapsed intervertebral disc I have seen fluid escape through a lumbar puncture hole in the dura made thirty-six hours previously. If the outward leak is severe enough the volume of fluid in the cisterns around the base of the brain becomes depleted: when the patient sits up the brain is no longer adequately cushioned and the drag on the pain-sensitive structures—the tentorium and large vessels—results in headache. The characteristic feature of this type of headache is that it bears a constant relation to posture; it is alleviated by lying down, aggravated by sitting up.

But the belief that escape of fluid is responsible for headache is not based on the effect of posture only. The headache can be relieved immediately, though temporarily, by the intrathecal injection of saline. The pressure of cerebro-spinal fluid in the vertebral canal in these cases is indeed low—almost invariably below 50 mm. water, sometimes unrecordable. Nevertheless, it is meaningless to refer to a "low-pressure" headache since the condition is greatly

aggravated if the intracranial pressure is increased by straining, or by gentle compression of the jugular veins. This no doubt causes the anchoring structures of the brain to be put still further on the stretch. In contrast to dural punctures elsewhere, cisternal puncture is rarely followed by headache. In the sitting patient the intradural hydrostatic pressure at this level is negligible, and the pressure in the extradural space is not negative as in the thoracic and lumbar regions; there is no reason, therefore, why there should be a continued escape of fluid through the puncture hole.

Prevention

The aim both of the technique of lumbar puncture and of the subsequent care of the patient should be to encourage the early closure of the defect in the dura. The main contribution the anaesthetist can make towards this is the prophylactic use of the smallest possible needle. Not only is the rate of fluid loss through a small hole very much less than through a large one, but the smaller hole heals very much more quickly. The needle should be introduced so that the bevel is parallel to the longitudinal fibres of the dura which are thus separated and not sectioned. Multiple punctures of the dura should be avoided, but if the point of the needle becomes blocked these can be made unwittingly since successful puncture is not proclaimed by issue of fluid. If a strict regime is instituted at once, and followed for twenty-four hours, the chance of headache is small; but this is not always practicable. Anything which raises the cerebro-spinal fluid pressure at the site of puncture will encourage loss and reduce the opportunity of healing. Coughing and straining are to be avoided. The patient should not be ambulatory, nor should he sit up. In fact he should lie down and the foot of the bed be raised so that the hydrostatic pressure in the lumbar region is negligible. A practical refinement is that the.patient, for periods as long as he can bear, should lie prone with the head at a lower level than the buttocks. This brings the hole in the dura uppermost.

Diagnosis

This presents no difficulty. The patient finds sitting up intolerable and soon discovers that he is reasonably comfortable only when lying down; often the horizontal position relieves the pain altogether. External stimuli in the form of strong light or loud

noise prove disturbing and add an element of irritability to the reigning depression. The patient dislikes movement, and is completely incapable of sustained effort involving muscular power. Thus reading is out of the question, and a man may have to interrupt shaving three or four times to lie flat for a few minutes.

Treatment

Once headache is established the results of active treatment are disappointing: but fortunately the slothfulness which accompanies the disability speeds recovery. The accepted pain-relieving drugs are strikingly ineffective. The intrathecal injection of saline affords passing relief but, as a therapeutic measure, the procedure is not to be recommended since it leaves an additional hole in the dura through which leakage can take place. The suggestion of Dr. Robert Hingson is a more rational one.[4] A catheter is introduced into and left in the extradural space. Saline is injected as required to give "a head of pressure" around the dura. The intrathecal pressure is thus raised and the symptom relieved until the hole in the dura heals. Care must be taken, however, not to injure the dura with the large needle through which the catheter is introduced! The patient should be encouraged to drink freely since this increases formation of the cerebro-spinal fluid. The regime described above, under the heading of prevention, should be followed to promote early healing of the dura: for once this is accomplished any deficiency in the volume of cerebro-spinal fluid is soon made good, and recovery is complete.

An aseptic meningeal reaction severe enough to cause headache, although formerly common, is now rare. When it does occur the condition clears up within a day or two without treatment, but in the meantime the patient may have to put up with a fairly severe headache which is unaffected by posture. Some degree of head retraction and malaise may arouse fears of septic meningitis: and if lumbar puncture is done to exclude this, it will be found that the fluid is under slight pressure and that the cell count is raised. It is wrong to refer to this condition as a high pressure headache. The discomfort is not influenced by posture nor relieved by withdrawal of fluid. It is extremely doubtful whether mere rise in pressure of cerebro-spinal fluid does cause headache. Symonds[3] reports a case in which saline was injected intrathecally and the

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patient's normal pressure of 170 mm. water was raised to, and maintained at, 550 mm. water for some minutes without causing symptoms: and there are pathological states which result in similar high pressures yet do not cause headache.

Although a good deal is known about post-lumbar puncture headache, the whole picture is not yet clearly defined. Why, when apparently identical techniques are followed, is one patient stricken while another remains immune? There is a general impression that headache develops more readily in neurotics, and it may be that in these a small stimulus provokes an excessive response. It would appear, too, that the symptom follows minor rather than severe operations: what is more certain is that patients in the first group tend to be ambulatory, while those who have had extensive operations have something more compelling than headache on which to focus their attention.

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CHAPTER IX

Do's, Don'ts, and Doubtfuls

Do's

IN any emergency do give oxygen—and do give it properly. Don't administer it uselessly by waving a funnel vaguely in front of the unfortunate patient's face, but employ some method which ensures that the oxygen reaches the lungs.

Do give oxygen, and tilt the head down *slightly* if the spinal block is high; the Trendelenburg position facilitates the return of venous blood to the heart and ensures a good arterial supply to the vital centres in the brain. These two measures are the best treatment for collapse, and the ones most calculated to prevent its onset. The main threat of high spinal analgesia comes from sub-oxygenation: and this results from a combination of the almost inevitable fall in blood pressure and diminished respiratory exchange, and itself leads to a greater fall in blood pressure and to a further decrease in respiratory efficiency—a vicious circle which, if not interrupted, can end fatally. Although the circle can be interrupted temporarily at various places, it can be broken most easily and effectively by giving oxygen. The question of raising the blood pressure by drugs is considered on page 136. Except in the case of patients with degenerative changes in the vessels, a fall in blood pressure *per se* does no harm for the short time the spinal anaesthetic acts. If for example, the pressure in the kidneys falls below that necessary for filtration and excretion of urine, no harm results provided the kidney tissues are kept well oxygenated. When the anaesthetic wears off, the pressure rises to normal, and the undamaged cells will function as before.

Do give oxygen throughout any abdominal operation carried out under spinal analgesia. Efficient respiration is menaced by many adverse factors, and the anaesthetist should see to it that these are not added to unnecessarily. The lower intercostal muscles, which have the same innervation as the muscles of the abdominal wall, are necessarily paralysed; and it is these which normally expand the lower and more mobile part of the thoracic

patient's normal pressure of 170 mm. water was raised to, and maintained at, 550 mm. water for some minutes without causing symptoms: and there are pathological states which result in similar high pressures yet do not cause headache.

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3 [illegible]
4 [illegible] -4
5 [illegible]
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as the foetus has been extracted, the unshackled diaphragm at once moves much more freely and it is not uncommon to hear the patient utter a sigh of relief, and exclaim, "That's better, I can breathe more easily now." Nevertheless, the disciplined anaesthetist continues with oxygen until it is clear that the patient will get on satisfactorily without it.

Some surgeons request a spinal anaesthetic because of the comparatively bloodless field which results from the low blood pressure. Others particularly ask that this method of anaesthesia should be avoided so that any cut vessels will be evident at this time. After spinal analgesia, the surgeon should make sure that any potential bleeding points are ligated; otherwise reactionary haemorrhage is more than possible.

Don'ts

In any emergency do not have faith in drugs: rely on lowering the head and administering oxygen, if necessary by artificial respiration. Carbon dioxide is particularly to be avoided if the patient's condition deteriorates under spinal analgesia. Normally this gas causes a rise in blood pressure since its central action of vasoconstriction predominates over its local action of vasodilatation. In the patient under a high spinal anaesthetic, however, any central stimulus cannot be effective since most of the effector pathways are out of action. The local vasodilator action of carbon dioxide is unopposed, and the lot of the patient is worse than before.

Never place ampoules of local anaesthetic solutions in alcohol, or antiseptics of any sort. This most dangerous practice is responsible for most, if not all, of the cases of permanent paralysis reported after spinal analgesia. At this hospital, some years ago, we kept glass ampoules containing procaine *crystals* for spinal analgesia immersed in spirit, in the unfounded belief that the ampoule could then be handled without fear of contaminating the hands during lumbar puncture. No harm came of this, but on two occasions I have picked out ampoules and found them to contain not dry crystals, but a liquid. Superficial inspection did not reveal any defect in the glass: but when the neck of the ampoule was sawn off, the contents were easily set alight with a match. A minute flaw in the glass undoubtedly existed, which may have been present before the ampoule was placed in spirit, or may have developed as a result of buffetings during the time it was submerged. In

cage. Ventilation now depends largely on the diaphragm : and the free movement of this is impeded if the patient is placed even in a moderate Trendelenburg position; for here the abdominal contents, *particularly if they include a large ovarian tumour or a full-time pregnant uterus*, provide no mean resistance to the action of this muscle. Abdominal packs and retractors, and a thoughtless surgical assistant who leans on the chest wall constitute additional respiratory affronts to which the hapless and helpless patient is only too often subjected. A combination of any or of all these factors may lead to a degree of respiratory embarrassment when the patient, breathing air, cannot keep her respiratory centre adequately oxygenated. The various compensatory mechanisms which normally come into play to deal with such a situation are out of action and the respiratory centre, already depressed by morphine, ceases to function. In practice, this unhappy sequence of events can be halted and the situation saved by allowing the patient to breathe a high concentration of oxygen throughout. The respiratory centre, the mainspring of respiration, is dependent not on blood pressure but on oxygen to keep it going. It is well known that the respiratory centre can continue in action even when the blood pressure is unrecordable: and this activity is maintained even though respiratory exchange is at a great disadvantage mechanically, provided the inhaled mixture is rich in oxygen.

The value of oxygen is exemplified, *par excellence*, in the operation of Caesarean section. Here under a spinal anaesthetic, many of the factors just enumerated contribute to make respiration difficult. If air only is breathed, the situation can soon get out of hand. Medical journals record only too many instances of rapid unexpected deaths in these circumstances. There is nothing baffling in these allegedly mysterious tragedies. There is nothing in the biochemistry of the pregnant woman which makes her peculiarly liable to collapse. *These deaths occur generally at the hands of a* junior anaesthetist working under instructions from the surgeon, and early in the operation before the foetus, a gross impediment to free respiration, is delivered. Indeed, what is strange is not that a few die " unaccountably," but that a large number survive such a combination of obvious respiratory insults. If the patient is given oxygen throughout, the picture is completely changed. The respiratory centre continues to function, and all is well. As soon

faulty ampoules had been stored. This protection must not be relied on. In connection with a recent legal case my colleague, Dr. Epstein, showed that ampoules could be contaminated with the coloured carbolic solution in which they had been stored without colour changes being apparent, particularly if the examination was carried out by artificial light.

Even when the colour of the added dye is intense the protection may be illusory. I have known the dye added to a bowl of uncoloured spirit in which ampoules had already been stored for weeks. In another hospital the practice was to store ampoules in uncoloured spirit and then to transfer them from this to a highly coloured solution shortly before use. In still another hospital a bowl full of ampoules, stored in alcohol, was pointed out to the nurse, and the danger explained. She took them out of the solution, but instead of discarding them out of hand, attempted to store them in a cupboard.

Do not give a high spinal anaesthetic to patients suspected of having certain vascular diseases, particularly cerebral arteriosclerosis or coronary thrombosis. Efficient circulation through the vessels in question is dependent on a good *vis a tergo*, or, in other words, on the maintenance of a good head of pressure. With high spinal analgesia some fall in blood pressure must be counted on: if this is severe enough to cause marked slowing of the rate of flow through the vessels, already narrowed and possibly irregular, thrombosis may result.

Be healthily suspicious of any container of "sterile" water to be used in spinal analgesia, and distrust completely a container which has already been opened.

Do not use "sterile" procaine from a stock bottle to make a skin wheal through which the spinal needle is to be passed. Open and use another ampoule of spinal anaesthetic solution for this purpose, or even omit the wheal altogether. Most local anaesthetics have a mild antiseptic action: but place no reliance on this virtue when spinal analgesia is being considered. During the War, at least two patients developed meningitis following the use of a "self-sterilising" proprietary local anaesthetic solution out of a stock bottle. A skin wheal was raised with this, through which the needle was inserted to perform lumbar puncture. Culture of the remaining solution revealed *Staphylococcus albus*, the organism

ampoules sealed under a partial vacuum, spirit would enter comparatively rapidly: in others the process might take many months. What had happened was plain at a glance, and the highly noxious contents were instantly rejected. But with conditions only slightly changed (Fig. 111) spirit can gain entrance into an ampoule without raising the slightest suspicion. This undoubtedly has happened after prolonged immersion in spirit of faulty ampoules of spinal anaesthetic *solutions*. If the flaw in the glass is gross, it is easy to visualise the influx of spirit. *It can take place equally certainly,* though more slowly, when the defect is too small to be detected by

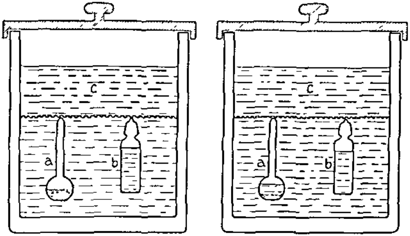

FIG. 111

the naked eye.[1] If the flaw is of molecular dimension, too small to allow the passage of liquids as such, diffusion of single molecules would take place in either direction. Water molecules effuse outwards, and alcohol molecules inwards; and the transfer continues until the liquids within the ampoule and outside it are the same. And since the volume of spirit in the outside container is so great, it follows that the ampoule eventually contains almost undiluted spirit. *But the eye will detect nothing to suggest that the contents* are other than what is indicated by the label. The innocuous-looking liquid now within the ampoule, reassuringly labelled, could cause permanent paralysis if injected intrathecally: and there would subsequently be no clue to the cause.

Caine[2] reports twelve cases, and Steinberg[1] four, where contamination of the local anaesthetic solution was revealed by discolouration from the artificially coloured antiseptic in which the

ment I think it right to stress that oxygen should be given throughout every spinal anaesthetic which reaches high enough to involve the intercostal muscles: and that the procedure should be limited to reasonably fit subjects, and avoided studiously in patients suffering from coronary disease or cerebral arterio-sclerosis. There is no reason why a "low" spinal anaesthetic, *i.e.*, one confined to the cauda equina for an operation on the legs or perineum should not be given to an ill patient.

A vasopressor drug with a central action cannot be effective in a high spinal block: for the effector pathways are out of action. I have been impressed by the unpredictability, and the transience of the effect of vasopressor drugs which act locally on the arterioles. And I doubt if the general condition of the patient some few hours afterwards is any better for the exhibition of the stimulant. Nevertheless, these drugs would appear to have a place where it is desired temporarily to raise the blood pressure, *e.g.*, to reveal any unligated vessels. There is another circumstance in which I have used a vasopressor drug. A spinal anaesthetic had been given for a Caesarean section just before a message arrived saying that the surgeon would be delayed for half an hour. By the time the operation was commenced the maternal blood pressure had fallen to 90 mm. Hg, and in view of the firm contraction of the uterine wall, any further fall might have prejudiced the blood supply to the placenta. The vasopressor drug in this case was administered because of danger, not to the mother, but to the foetus.

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with which the patients were infected. Subsequently it was shown that bacteria introduced experimentally into similar bottles of local anaesthetics survive for several hours, and even for days.

Doubtfuls

It is commonly stated that a spinal anaesthetic should not be given to patients suffering from diseases of the central nervous system. It may be politic to accept this view, since any exacerbation may be blamed not on the natural course of the disease, but on the administration. Nevertheless, I find it impossible to believe that a spinal anaesthetic will cause any more harm than the lumbar puncture which is made as a routine in the investigation of these diseases. I have, in fact, given a spinal anaesthetic to a patient suffering from tabes and to another suffering from syringomyelia, and there was no suggestion that either was any the worse for the experience. It may not be advisable to go out of one's way to choose this method of anaesthesia, but I can see no reason why these patients should be deprived of any particular advantages which spinal analgesia may offer for the relief of their surgical disability.

I have no personal knowledge of the effect of spinal analgesia in shock, but it gives me the impression of being a blunderbuss method, incapable of refinement. Hewer[3] goes further and regards the procedure as tantamount to signing the patient's death certificate. A professional anaesthetist confronted with a shocked patient would choose a general anaesthetic: for the depth of this can be controlled and varied to suit the changing condition of the patient and the surgeon's requirements. There can be no doubt that if the patient is fit enough to stand a spinal anaesthetic, he is fit enough for a general anaesthetic properly administered. On the other hand, an ill patient can easily die if the general anaesthetic is not given skilfully. In an emergency therefore, where an experienced anaesthetist is not available, it may be justifiable to give a spinal anaesthetic paying particular attention to keeping the head low, to giving oxygen throughout, and to the avoidance of so-called stimulating drugs.

Whether vasopressor drugs have any merit in spinal analgesia is an old controversy. Some anaesthetists use them as a routine, others actively avoid them and yet achieve satisfactory results. I include myself in the latter group: but in making this state-

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